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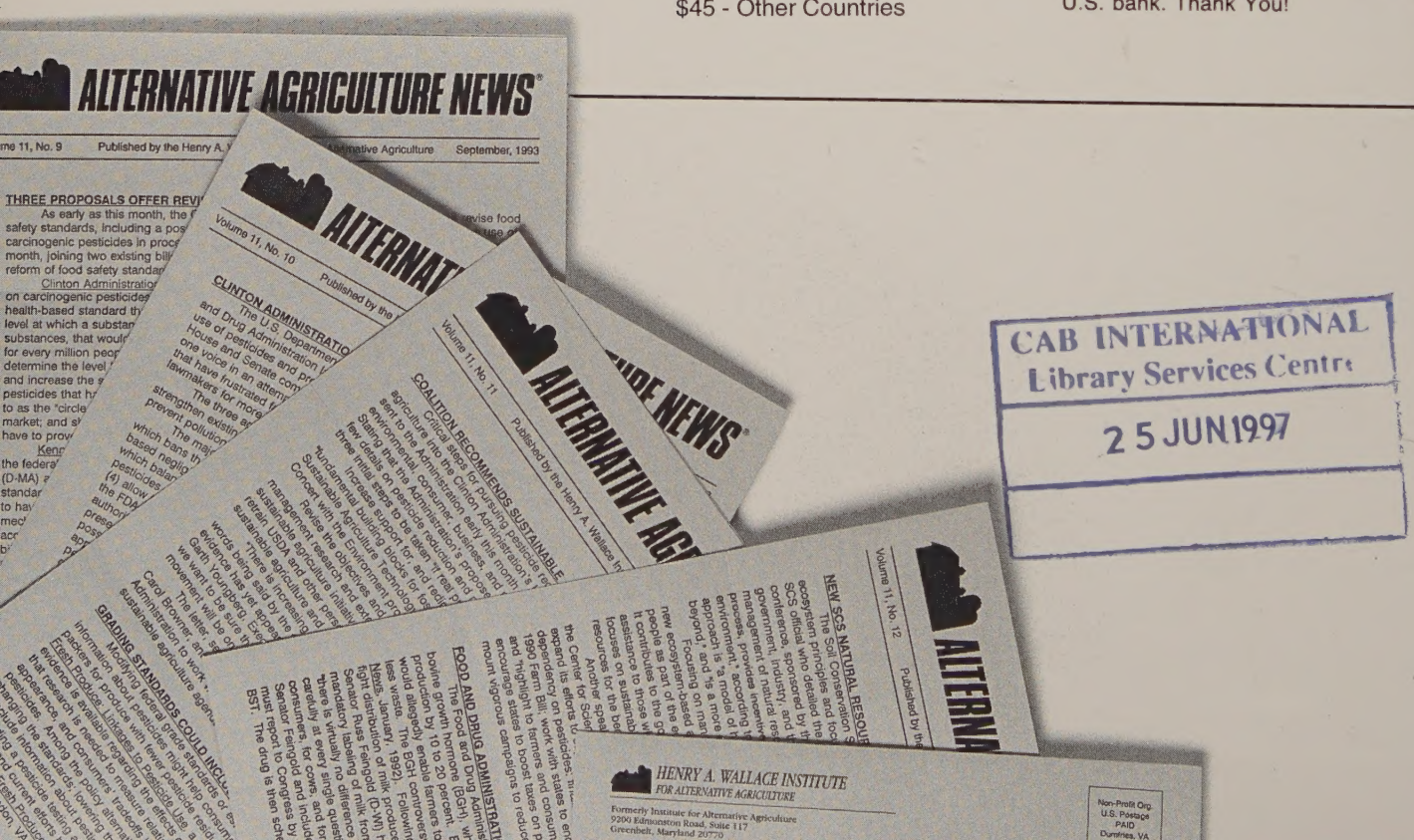

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The Henry A. Wallace Institute for Alternative Agriculture is a nonprofit, tax-exempt research and education organization established in 1983 to encourage and facilitate the adoption of cost-effective, resource-conserving and environmentally-sound farming methods. It works closely with producer groups, public research and education institutions, and government agencies in promoting a sustainable agriculture system.

Its programs include providing a national information clearinghouse, serving as a voice for sustainable agriculture in Washington, and developing and implementing research and educational outreach programs. It holds an annual scientific symposium and publishes a monthly newsletter.

The Institute is governed by a grass roots Board of Directors, which includes several commercial-scale organic farmers, and maintains a small professional staff. It is supported by memberships and donations and grants from foundations, corporations, and individuals.

Cover Photo

Contour stripcropping and grass strips reduce water erosion in the Palouse area of eastern Washington. Photo provided by the Natural Resources Conservation Service.

Introduction: Improving the sustainability of dryland farming systems

Robert I. Papendick and James F. Parr

Water shortages are reaching a critical stage in many Middle East countries, and competition for water continues to become more intense as population growth and rising demands stretch supplies to their limits. This has had a serious impact on irrigated agriculture, which has been a mainstay of food production throughout the region. Although water is a renewable resource, it is nevertheless finite, and in some countries, such as Israel, annual water use already exceeds the renewable supply. There is little doubt that future cutbacks in water supplies will limit production from irrigated agriculture. Food, feed and fiber deficits from a decline in irrigated crop production will likely increase the role of dryland agriculture. This will place a greater burden on dryland ecosystems that often are fragile and easily degraded by intensive farming practices. Thus, there is an urgent need to develop soil and water conservation methods and cropping practices that are productive and sustainable in the long run.

Traditionally, much of the emphasis in agricultural development in the Middle East has been on expanding and improving irrigated systems. Because of lower yields and higher risks, dryland/rainfed agriculture has received much less research attention. As a result, dryland crop production has remained consistently low compared with intensive irrigated agriculture. Often the genetic potential of improved crop varieties is not achieved under dryland conditions because of the lack of appropriate management practices. To achieve optimum and sustainable crop production, research is needed to determine the best combinations of soil and water conservation practices, planting methods, adapted varieties, pest control, and fertility management.

Farmers in the dryland areas of the U.S. Pacific Northwest and the Middle East face many similar problems in production, resource conservation and environmental protection. Both regions have winter precipitation patterns, low and unpredictable rainfall, light-textured soils subject to wind and water erosion, and cereal-based cropping systems for food and forage production. These similarities and challenges provide an ideal setting for sharing knowledge and experiences, and for developing collaborations between U.S. and Middle East dryland experts that promote technologies for improving dryland farming capabilities while enhancing long-term sustainability.

Consequently, U.S.-Middle East Conference and Workshop was held on "Dryland Farming Systems and Technologies for a More Sustainable Agriculture" at Moscow, Idaho, on October 18–23, 1993. This landmark event was conducted under the auspices of the Multilateral Working Group on Economic Development of the Middle East Peace Process. Participating U.S. agencies and institutions included: USDA's Agricultural Research Service, Economic Research Service, Office of International Cooperation and Development, and Soil Conservation Service; the U.S. State Department; the University of Idaho; Washington State University; and Oregon State University. The conference/workshop was attended by approximately 50 scientists representing the U.S., Russia, Egypt, Israel, Tunisia, Turkey, Jordan, Oman, and the emerging Palestinian State.

The participants offered their expertise in comprehensive presentations on different aspects of sustainable agriculture and dryland farming systems and technologies. Research topics included field application of soil and water conservation practices and technologies, improvement of soil quality to enhance agricultural sustainability, pest management strategies for conservation farming, integration of crop and livestock farming systems, applications of modeling and geographical information technologies to improve dryland farming systems, and overcoming economic, social and production constraints of dryland farming systems.

The 13 conference papers by U.S. scientists are presented here. Six additional papers by international authors will be published in a later issue. In his introductory paper, R.I. Papendick discusses the major constraints of soil erosion and loss of soil quality with intensive tillage practices, and the need for developing continuous no-till systems to achieve sustainability. The paper by J.E. Hammel emphasizes that both water conservation practices and effective residue management for protection of the soil resource are required to achieve long-term sustainable production. However, K.E. Saxton points out that sustainability goes beyond just protection of the soil resource, because wind erosion and farmland dust may damage off-site air quality in urban and rural areas.

Advances in dryland conservation crop production technologies are comprehensively described in papers by F.J. Muehlbauer on cool season legumes, L.F. Elliott and P. Chevalier on crop diversification, D.E. Wilkins on tillage/planting/fertilizing methods, E. Donaldson on crop traits for water stress tolerance, R.W. Smiley on the constraints of crop diseases, and K.S. Pike and

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L.K. Tanigoshi on insect control. These papers discuss various opportunities for dryland crop improvement through breeding; improving soil quality and pest control, and reducing the need for chemical inputs through crop diversification; meeting equipment needs for conservation farming; and disease and insect hazards with dryland conservation systems and pest management strategies to maintain long-term agricultural sustainability.

Soil fertility management is an important consideration in the development of practical conservation systems that will enhance the sustainability of dryland farming systems. This is discussed by P.E. Rasmussen, who emphasizes the importance of proper soil fertility to reduce weed competition and damage from root-pruning plant pathogens. He points out that adoption of conservation systems over entire fields can alter soil fertility and the soil water conditions to differing degrees across the landscape. This issue is dealt with in greater detail by C.O. Stockle who describes how geographical information systems and simulation technologies can help in defining the temporal and spatial variability of environmental conditions at the farm and field level and in identifying biophysical constraints to crop production and resource management.

Integration of livestock production with range and crop management is a major issue in the Middle East, but less so in the U.S. Pacific Northwest. However, as L.H. Hardesty and J.A. Tiedeman point out, creating a more sustainable agriculture may sometimes lead to reintegrating livestock into our cropping systems. They describe the major obstacles to achieving this, including the lack of information to help farmers make integration profitable, lack of infrastructure, problems with chemicals used on crops that are fed to animals, and balancing year-round forage supplies.

D.L. Young addresses the economic impacts of the various contributions to multidisciplinary agricultural systems research. He provides examples of how economic analysis has been an integral part of several successful multidisciplinary research efforts in the U.S. Pacific Northwest. Young's message to this conference was that properly designed economic analysis can make a major contribution to identifying successful dryland agricultural technologies for both the Middle East and U.S. dryland areas.

Acknowledgments. We gratefully acknowledge USDA's Office of International Cooperation and Development (OICD) and the U.S. State Department's Bureau of Oceans, Environment and Science, which provided grant funds for planning and conducting this conference/workshop and for publishing the proceedings. The assistance of Ms. Eileen Herrera, Program Specialist, OICD, in planning and conducting the conference/workshop is acknowledged with our sincere thanks and appreciation. Lastly, we wish to thank the anonymous reviewers who contributed generously of their time and effort in reviewing the manuscripts in this issue.

U.S. Agriculture "Must Be Sustainable," Says President's Task Force

"U.S. agriculture must be sustainable if the national goal of sustainable development is to be achieved," and should be supported with research that integrates "agricultural productivity and profitability with environmental stewardship," according to the report of the Sustainable Agriculture Task Force of the President's Council on Sustainable Development. Chartered by the President's Council in 1994, the Task Force was charged with "articulating the key social, economic, and environmental challenges to be met in achieving a sustainable U.S. agriculture."

In its report released last month, the Task Force defines four goals for sustainable agriculture, and nine recommendations on how to achieve those goals. The four goals are:

- Management of agricultural activities to protect air, soil, and water quality, and to conserve wildlife habitat and biodiversity, thereby increasing agriculture's long-term productivity and profitability, as well as enhancing human health and well-being.
- Achievement of viable farmers and farm communities.
- Production of a safe, high-quality, and affordable supply of food and fiber in a manner that protects and conserves natural resources.
- Creation of institutional incentives and funding arrangements that focus public and private research, education, and technology development on integrating agricultural productivity and profitability with environmental stewardship.

The Task Force's recommendations are "bold first steps in accomplishing these goals," according to the Task Force Report. In the report, each recommendation includes "a discussion of the concerns that inspired it" and "yardsticks for measuring progress in meeting a particular goal." The recommendations are:

- Harmonize the pollution prevention and natural resource conservation policies of various federal, state, and local agencies to minimize conflicts among the policies that could undermine environmental protection.
- Increase the flexibility for participants in commodity programs to respond to market signals and adopt environmentally sound production practices and systems, thereby increasing profitability and enhancing environmental quality.
- Expand agricultural markets to increase demand for agricultural products, returns for farmers, investments in environmental protection, and conservation of natural resources.
- Move the pricing of public natural resources and their use toward market pricing.
- Keep prime farmlands in agricultural production by implementing rational land-use policies such as easement, zoning, taxation, financial incentives, transportation, and land development policies that reduce the encroachment of urban sprawl on prime farmlands.
- Help rural communities to capitalize on the economic benefits of sustainable agriculture by giving priority in rural business development and marketing programs to investments in enterprises associated with the products of sustainable agriculture.
- Continue improvements in food safety and quality.

For a copy of the Sustainable Agriculture Task Force Report, contact the President's Council on Sustainable Development, 730 Jackson Place, NW, Washington, D.C. 20503; (202) 408-5296; Internet address http://www.whitehouse.gov/pcsd

Farming systems and conservation needs in the Northwest Wheat Region

R.I. Papendick

Abstract. *The Northwest Wheat Region is a contiguous belt of 3.3 million ha in Idaho, Oregon and Washington. Its climate varies from subhumid (<650 mm annual precipitation) to semiarid (<350 mm), with more than 60% of the annual precipitation occurring during the winter. Winter wheat yields range from a high of 8 t/ha in the wetter zones to a low of 1.5 t/ha in the drier zones. Winter wheat is grown in rotation with spring cereals and pulses where annual precipitation exceeds 450 mm; winter wheat-fallow prevails where annual precipitation is less than 330 mm. Tillage practices are designed to maximize infiltration and retention of water through soil surface and crop residue management. Because of the combination of winter precipitation, steep topography, and winter wheat cropping, much of the region is subject to a severe water erosion hazard, accentuated by freeze-thaw cycles that increase surface runoff and weaken the soil structure. Wind erosion is a major problem in the drier zones, where cover is less and soils are higher in sand. Residue management, primarily through reduced tillage and no-till systems, is the first defense against both wind and water erosion, but yields often are higher with conventional intensive tillage. Factors that limit yields with conservation farming include weed and disease problems and the lack of suitable tillage and seeding equipment. Conservation strategies must shift from relying on traditional tillage methods to development of complete no-till systems. Spring cropping as a replacement for winter wheat also needs to be investigated. In some cases, tillage for water conservation must be made compatible with tillage for erosion control.*

Key words: winter wheat, winter rainfall, conservation tillage, fallow, water erosion, wind erosion, soil quality, cropping systems, Pacific Northwest

The Agricultural Setting

The heart of the Northwest Wheat Region is a belt of about 3.3 million ha extending across northern Idaho, eastern Washington, and north central Oregon (Papendick et al., 1983). Because of high rates of wind or water erosion, to be eligible for government farm program benefits more than 60% of its farmers must implement a conservation plan that will significantly reduce soil erosion from pre-1985 levels.

Major products

Winter wheat (*Triticum aestivum* L.) or its replacement, spring wheat, is the dominant crop in all areas, with about 48% of all cropland planted to wheat each year. Of this, more than 80% is soft white; the remainder is hard red, which is grown in the drier areas. Total wheat production in this region usually exceeds 8 million metric tons annually (U.S. Dept. of Agriculture, 1993), of which 80 to 90% is exported. Pea (*Pisum sativum* L.), lentil (*Lens culinaris* Medik), and winter rapeseed (*Brassica napus* L.) are important in the higher precipitation zones. Barley (*Hordeum vulgare* L.) is grown in all areas, but to a lesser extent in the drier zones.

Livestock production is less important than crop production, and is not usually mixed with it. Cattle ranching and feedlot operations are the main animal enterprises. There are a few large sheep operations on rangelands, but the number of sheep has declined in recent years. Sheep sometimes are used to graze crop aftermath in the irrigate areas. A small portion of unirrigated cro stubble is grazed by cattle in transitional area between cropland and rangeland.

Climate, topography and soils

The climate varies from semiarid at th western edge to subhumid near the moun tainous areas to the east. Altitude range from 300 to 1400 m. The entire wheat re gion has a Mediterranean-type climate: win ters are wet and cold, summers dry an warm to hot. Between 60 and 70% of th annual precipitation falls between Novem ber and April. Mean annual precipitatio ranges from about 230 mm in the south western part (wheat-fallow zone) to mor than 650 mm in the northeastern part of th region, where the elevations are higher Snowfall is 20 to 25% of the total precipita tion at the higher elevations and decrease from the north and east toward the soutl and west. The soil may freeze to a depth o a few to 10 cm several times each winter and to 40 cm or more during some winters There are frequent freeze/thaw events whe the soil is at or near saturation; in combina tion with rain or melting snow they greatl exacerbate the erosion hazard. Though rainfall intensity is low (less than 5 mm/hr) considerable runoff can occur while the soil are frozen, especially when they are covere with snow.

The region also is subject to high wind in the spring and fall. This creates a win erosion hazard in the drier areas, where residue cover is sparse and soils are sandie than the silt loam soils in the higher precipi tation zones. Because of the rolling topogra phy, surface wind speeds and turbulenc vary across the landscape, making some area more prone to wind erosion than others

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Wind erosion has not yet been studied in the region except for some estimates of soil loss during high winds with certain farming practices.

The topography in the higher precipitation areas is steeply rolling, with dune-like hills and steep north and east slopes. Most slopes range from 8 to 30%, but slopes greater than 45% are cultivated. On these lands, water erosion can be severe. In the drier areas the topography is more gently rolling; less land is classified as highly erodible by water, but more by wind.

The region's soils are derived from loess mixed with varying amounts of volcanic ash. When not restricted by a hard frost layer, they generally are permeable and well drained, and can adequately store the annual precipitation. Some soils in north central Oregon are shallow and have less moisture storage capacity. Soils tend to be sandy in the drier areas, grading to silt loams and silty clay loams in areas with increasing precipitation. Further details on climate, topography and soils of the Northwest Wheat Region can be found in McCall and Holtz (1921), Horner et al., (1944), and Naffziger and Horner (1958).

Crop and Soil Water Relations

A guideline for optimally fertilized winter wheat in the Pacific Northwest is that it takes 100 mm of available water for a crop to grow to anthesis; 17 kg/ha of wheat is produced for each additional 1 mm of available water (Leggett, 1959). However, excess nitrogen fertilizer can reduce water use efficiency (crop productivity per unit of uptake of water), especially in dry years; it also can raise the protein content of soft white wheat to undesirable levels (Rao et al., 1993). Available water is the soil moisture measured around April 1, plus rainfall in April, May, and June, minus the soil moisture that remains after a wheat harvest, to a depth of 1.8 m or the rooting depth.

A healthy crop of winter wheat usually will extract water from an average rooting depth of 1.8 m to a limit that depends on the soil texture and profile. If wheat growth is not limited by anomalous weather or management, or by disease and insect infestations, the crop will use all the available water at maturity. An almost constant amount of water remains in the profile after every wheat crop. The lower limit of extraction for most other crops is higher than for winter wheat. At full recharge (late March) soils in the high precipitation zone (50 to 60% silt, 10 to 20% clay) will hold a maximum of about 34% water by volume, or about 600 mm to a depth of 1.8 m. Soil water storage from October through March with annual cropping averages about 60% of the total precipitation. The soil profile may not be fully recharged in the spring of the crop year because actual storage depends on the previous crop, winter precipitation, and storage efficiency. For example, values of 500 to 540 mm (28 to 30% by volume) are common in the 1.8-m profile at the end of the winter rainy season for winter wheat following peas. The lower limit of water extraction in these soils for winter wheat is about 270 mm in the 1.8-m rooting depth, meaning that at the beginning of the growing season there is 230 to 270 mm of available water stored. With favorable weather, the available water in a fully recharged profile plus average spring rainfall can produce a grain yield of up to 7 t/ha, and up to 9 t/ha with above-normal growing season precipitation.

In areas of lower precipitation, where soils are sandier (60 to 70% sand, 5 to 8% clay), the maximum water holding capacity is 400 to 450 mm and the lower limit of extraction is about 165 mm. This results in available water storage capacity of 235 to 285 mm. Field data show soil water depletion by winter wheat is often about 200 mm or less, which is below the storage capacity. Available water is limited to this amount by the precipitation (unpublished data by the author). With average spring rainfall and growing conditions, this amount of stored water will produce wheat yields of 2.5 to 3 t/ha.

Farming Systems

Cropping systems in the Northwest Wheat Region are determined primarily by annual precipitation. The region's croplands are generally divided into three precipitation zones: high (>430 mm), intermediate (330 to 430 mm), and low (220 to 330 mm). The cropping sequences discussed below for each precipitation zone are largely determined by climate and soils.

Farming in this region, as in most of the nation, is highly mechanized, requiring a high level of capital and external inputs such as fuel, fertilizers and pesticides. Farmers' usual goal is to produce maximum yields. For example, in the high precipitation zone, a nitrogen application of 160 kg/ha is required for maximum yields of winter wheat. The rate decreases to 50 to 60 kg/ha in the low precipitation zones. Mechanization offsets the need for labor, which varies seasonally, especially on large commercial operations. Tractors range from 250 to 350 horsepower and cost more than $100,000; with a 10-bottom moldboard plow they can till up to 3 ha/hr, or with a 10 to 15 m wide field cultivator up to 7 ha/hr. Harvesting machines up to 10 m wide, costing $200,000, can harvest 33 t of wheat per hour. Individual farms, which often are family operations run by two or three persons, average 400 to 600 ha in the high precipitation zone to more than 1,000 ha in the low precipitation zone. The crop mix usually is less diverse on larger farms and in the lower precipitation zones.

High precipitation zone

In the high or subhumid precipitation zone, farmers generally raise a crop every year, most commonly winter wheat in rotation with spring crops of pea, lentil, barley or wheat. In this zone, winter wheat accounts for about 50% of cropland, pea or lentil 20%, spring barley or wheat 20%, and forage or occasional fallow 10% (Papendick and Moldenhauer, 1995). Farmers generally use two- or three-year rotations, but there is some continuous cropping of winter wheat. The cropping system is influenced by wheat and barley bases, that is, the maximum area established by the government from cropping history that the farmer can plant to that crop and remain eligible for farm program benefits. If the farmer plants less than the base, it may be reduced in later years; a farmer who plants more than the base is ineligible to receive subsidy payments. The three-year rotation of wheat-barley-pea (or lentil) has gained popularity mainly for weed and disease control. However, many farmers are limited to a two-year rotation of wheat-pea (or lentil) or continuous cropping on at least part of their farms to maintain their base. Cropping sequences used by farmers in this zone are listed in Table 1.

Wheat yields range from 2.5 to more than 4 t/ha in the less productive areas

Table 1. Crop sequences for the high precipitation zone[1].

Three year rotation
Winter wheat-spring cereal-pea (or lentil)
Winter wheat-spring cereal-spring canola
Winter wheat-fallow-winter rapeseed
Two year rotation
Winter wheat-pea (or lentil)
Continuous cereal cropping
Winter wheat-winter wheat (minor)
Winter wheat-spring cereal

[1] Occasionally, fall barley is substituted for winter wheat.

(ridgetops and upper slopes), and from 5 to more than 8 t/ha in the more productive lower slopes and bottom lands (Papendick and Moldenhauer, 1995). Corresponding crop residue yields are from 3 to more than 5 t/ha in the former and from 6 to more than 10 t/ha in the latter. Grain and residue yields from spring cereals are 50 to 70% those of winter wheat. Lentil and pea grain yields average 1.5 and 2 t/ha, respectively, and residues for both are about 1.5 to 2 t/ha at harvest (Papendick and Moldenhauer, 1995). Pea and lentil residues degrade more rapidly than cereal residues, and therefore are less effective in controlling erosion than an equal initial mass of cereal residues.

Moldboard plowing has been the traditional primary tillage practice in this zone, with much of the winter wheat stubble plowed before winter. However, use of fall chiseling with modified shanks is increasing as more farmers are adopting surface residue management practices for erosion control. Secondary tillage for weed control and seedbed preparation is accomplished in several operations with a field cultivator or rodweeder, and a harrow. Where winter wheat follows a spring crop, disking is favored as the primary tillage for seedbed preparation. With conventional systems all planting is done with double disk drills with 15 to 18-cm row spacings.

Winter wheat is sown from late September to mid October. There usually is little growth and therefore little ground cover before the temperature falls below freezing in late November or early December. Winter wheat is largely dormant from December until March; as with spring crops, most growth occurs from April to mid-July on residual soil moisture.

Intermediate precipitation zone

The two most common cropping systems in the intermediate precipitation zone are winter wheat-spring barley-fallow, or winter wheat-fallow in the drier areas. In this zone, winter wheat is grown on about 45% of cropland, spring barley or wheat on 20%, and fallow on 35%. In recent years a small amount of spring canola (*Brassica napus* L.) has been grown in place of spring barley or wheat in the three-year rotation, and spring wheat occasionally is substituted for spring barley. The two-year winter wheat-fallow system has increased risks of diseases and grassy weeds compared with the three-year rotation because of the higher frequency of winter wheat. Moreover, the critical erosion period with winter wheat after fallow occurs every second year in the wheat-fallow system instead of every third year, which increases the potential long-term average annual erosion.

There is some successive cropping of spring cereals, either spring barley or spring wheat. This is most common in areas where rotations with winter wheat planted on fallow are limited by shallow soil, low residue production and water storage potential, or high erosion potential. Water conservation over winter and in the spring is critical for successive spring cropping of cereals. However, this sequence is particularly advantageous in areas infested by downy brome (*Bromus tectorum*) or jointed goatgrass (*Aegilops cylindrica*). These winter annuals can be readily controlled and their seed banks reduced with spring cropping.

Winter wheat on ridgetops, upper south slopes and other less productive parts of fields produce from 1.7 to more than 4 t/ha of grain and from 2.2 to more than 5 t/ha of crop residue (Papendick and Moldenhauer, 1995). On lower slopes, bottom lands, and other more productive areas, grain yield ranges from 4 to more than 6 t/ha, with a straw yield of 5 to 8 t/ha. Barley grain yield ranges from 0.6 to 1.2 t/ha in the less productive and from 2 to nearly 4 t/ha in the more productive areas. Barley produces less residue, and its residues decompose faster than wheat residues. Therefore, barley requires extra attention in managing residues for erosion control, especially where barley is followed by a year of fallow.

Traditional tillage practices after winter wheat in the three-year rotation include moldboard plowing in the moister areas and a combination of disking and chiseling in the drier areas. However, surface residue management is gaining acceptance because of conservation, and moldboard plowing is declining. Secondary tillage in the spring before spring barley is planted may include two to three passes with a field cultivator and harrow followed by the fertilizer applicator, rodweed/harrow, and seeding with double disk drills or hoe-type drills.

The fallow part of the rotation begins after the barley in most three-year rotations or after the winter wheat in the two-year rotation. In either situation, the crop stubble may be disked or chiseled in the fall after harvest or left standing over winter. Fall tillage is used to promote overwinter infiltration into frozen soils where this is of benefit, and to control weeds. When there is less than 3 t/ha of residues, chiseling is favored because it conserves more residues on the surface, whereas a combination of disking and chiseling is used with higher amounts of residues to incorporate more of them. Secondary tillage is accomplished with a rodweeder to control weeds and maintain a loose soil mulch 10 to 12 cm deep to conserve seedzone water. Double disk, hoe and deep furrow drills are all used for sowing. Occasionally, no-till drills are used with no-till fallow, but this practice is not common. The choice of drill is determined by average moisture conditions: the double disk drill is used where moisture is adequate, while the deep furrow drill is used where seedzone moisture lies deeper, so that the seed must be placed 12 to 15 cm below the surface for rapid germination.

There is increasing interest in continuous cropping in the intermediate precipitation zone as a way to keep more cover on the land for reducing soil erosion and to increase water use efficiency by eliminating evaporation losses during fallow. Continuous cropping has been most successful with no-till because of better water conservation. Weeds are controlled with nonselective contact herbicides, and the crops are sown with a no-till drill that can apply fertilizer and place seeds through moderate amounts of crop residues. A fall crop may be sown if moisture is sufficient to permit weed control and seed germination before winter; if not, planting can be delayed until spring. Tillage generally is unsuccessful with continuous cropping because it increases the risk of

moisture deficits in an area where water usually limits crop production.

Low precipitation zone

Winter wheat-fallow is the most widespread practice in this zone. No other cropping system has as low a risk of crop failure and as great a chance of being profitable year after year. Fallow water storage efficiency from the summer after wheat harvest to the spring of the crop year (20 months) averages 50%, which is sufficient to stabilize crop yields at economically adequate levels (Ramig et al., 1983). Nevertheless, as in the intermediate precipitation zone, there is growing interest in annual spring cropping in situations where soil texture or a shallow profile limits water storage. In these cases, no-till spring wheat may be the most successful. Weeds are controlled through effective use of herbicides. There is evidence from farmer experience that weeds become less of a problem after several years of continuous no-till cropping.

Winter wheat grain yield in this zone ranges from 1.3 to 4 t/ha, with residue yield from 1.5 to 5 t/ha. Where spring wheat is cropped annually, grain yield ranges from 0.8 to 2 t/ha, with residue yield from 1 to 2.5 t/ha.

Water conservation is critical, so that tillage is aimed at increasing water infiltration and retention in soil, and controlling wind erosion. Maintaining a sufficient amount of crop residue on the surface is a key strategy.

Grain stubble in the wheat-fallow system is usually left standing over winter unless weed control or runoff from frozen soil is a problem. Russian thistle (*Salsola iberica* Sennen & Pau) can be a major weed problem after harvest. It is best controlled by undercutting the stubble with a field cultivator equipped with duck-foot sweeps or Noble blades that kill weeds but leave the stubble standing. Farmers sometimes do light tillage with a harrow, disk or skew treader to incorporate weed seeds in the soil and thereby initiate winter germination. This aids weed control in the spring. Except when it reduces runoff from frozen soil, any fall tillage reduces overwinter water storage compared with leaving the stubble standing undisturbed.

Fallow tillage in this zone is similar to tillage in the drier end of the intermediate precipitation zone. The primary tillage tool is the chisel or sweep plow, with the first operation taking place as early as February. Some farmers are shifting to pre-tillage herbicides so that the first tillage operation can be delayed. Any delay in spring tillage helps conserve surface residues and thus enhances water conservation and erosion control. Secondary tillage is two or three passes with a rodweeder to control summer weeds and maintain a loose soil mulch 10 to 13 cm deep to conserve seedzone water.

Chemical fallow instead of tillage has not gained much acceptance in the dry areas. One reason is that farmers can increase their grain yields by 30% or more by getting a crop established in late August or early September by seeding into moisture carried over through the dry summer. With chemical fallow or untilled soil, the seedzone dries out during the summer and a crop cannot be established until fall rain occurs, which usually is not until late October or early November. Yields are much less with these late seeding dates. With tilled soil, seedzone water can be conserved for early crop establishment. Herbicide costs also limit the use of chemical fallow in the low rainfall areas.

Sowing into fallow is done almost exclusively with deep furrow drills that can place the seed 15 cm below the surface into moist soil. Row spacing is 40 to 45 cm to accommodate soil and residues between the furrows. Drills have been modified to handle surface residues and to create berms in the furrow seed row that act as small reservoirs to prevent runoff. Fertilizer usually is applied in a separate operation ahead of sowing, but some farmers have modified their drills to sow and fertilize simultaneously.

A few farmers have adopted no-till continuous spring cropping in the low precipitation zone. Wheat is sown as early as conditions allow, which is usually by mid to late February. No-till allows earlier planting than with tillage because no time is taken for seedbed preparation and extra passes. Because of water conservation benefits, no-till also reduces the risk of crop failure. Nonselective herbicides are used as needed to control weeds. Spring cropping reduces problems with winter annual grassy weeds and some foot rot diseases. The major weed is Russian thistle, which can be economically controlled with herbicides.

Conservation Needs

The climate and the steep topography create major winter runoff and erosion problems with the winter wheat-based cropping systems in the high and intermediate precipitation zones. In the low precipitation zone, water erosion is less severe and is easier to control. There, the major concerns are wind erosion and insufficient water.

Higher precipitation zone

With poor management, soil erosion in the high precipitation zone can exceed 350 t/ha on some slopes in a single season, with annual field averages of 27 t/ha (Papendick and Miller, 1977; U.S. Dept. of Agriculture, 1978). Major erosion events are usually associated with frozen and partially thawed soils. The erosion is caused mainly by runoff from rain or melting snow. Raindrop impact or splash erosion contributes little because the rain is of low intensity.

Residue management in combination with reduced tillage is the first defense against erosion, which is the leading cause of soil degradation. Surface residue management is highly effective for controlling runoff-induced erosion. It is less effective against splash-induced erosion, which is the main cause of erosion with the high rainfall intensities in the central U.S. (Fig. 1). However, conservation tillage, which is based on managing surface residues, is not well accepted in the Pacific Northwest because farmers can often achieve higher yields with conventional clean tillage. Yield limitations are generally ascribed to unsolved weed and disease problems and to the lack of suitable tillage and seeding equipment for conservation farming. Equipment may be available, but many farmers lack the capital to make the changes, or are unwilling to do so because they fear increased risks from other yield-limiting factors, such as pests.

No-till has not been well accepted in the region and has never been used on more than a small fraction of the planted area (my own observation and personal communication with staff of the USDA Natural Resources Conservation Service). More farmers are employing various forms of reduced tillage with some success. No-till and reduced tillage are likely to be more successful with rotations and greater crop diversification. However, with wheat-based cropping systems, there are few alternatives to cereals, except grain legumes.

Surface roughness, green cover, strip cropping and uphill plowing (depositing the

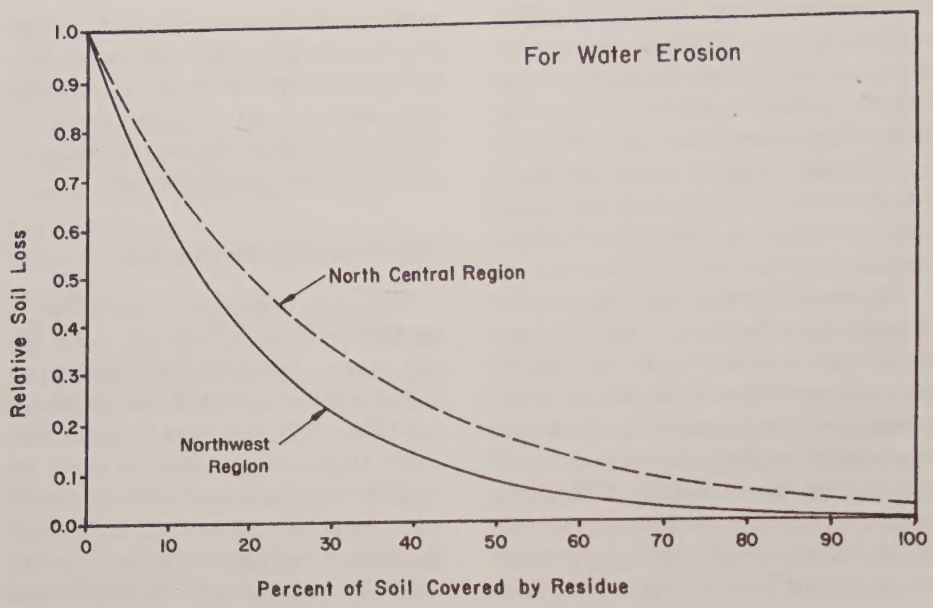

Figure 1. Relationship between residue cover subfactor and percent small grain residue cover for North Central and Pacific Northwest conditions (Papendick and Moldenhauer, 1995).

furrow slice uphill) all are effective for erosion control, especially when used in combination with surface residues. The main conservation research needs in the higher precipitation zone include evaluating the effectiveness of various individual erosion control practices and determining their additive (or multiplicative) effects when applied in combination. Second, we must learn the agronomic effects of these conservation practices that limit crop yields and their other mechanical or economic effects that may limit their adoption, either individually or in combination. Conservation research often has lacked economic assessments of individual practices or complete farming systems. These are urgently needed as part of current studies to help determine the practical usefulness of the research results to farmers.

Lower precipitation zones

Wind erosion with conventional fallow can exceed water erosion in the higher precipitation zones. I have seen fields in south central Washington that lost between 4 to 10 cm of topsoil (equivalent to 240 to 600 t/ha) from wind erosion from fall to spring in 1990–91. Evaporation is the major cause of water loss, with as much as three-fourths of annual precipitation lost from a bare, uncropped soil. Potential evaporation is highest during the summer months, but the highest losses occur during the spring when the soil surface is moist and the soil is slowly warming. This period and the winter rainy season are the times when surface cover is most important for reducing evaporation losses.

Fortunately, surface cover works both to control wind and water erosion and to increase water storage and retention. Residue management problems in the dryland areas arise from the low amount of residues produced and their decomposition and destruction by repeated tillage during the long fallow. Each field cultivation reduces residue cover by 15 to 20% (Papendick and Moldenhauer, 1995). With fallow systems that use a primary tillage operation in the fall or spring followed by three to five summer rodweedings, often little residue cover is left by seeding time.

Conservation strategies need to focus on less tillage and on using wider spaced shank tools on chisel implements where tillage is needed to improve infiltration into frozen soils. Where feasible, primary tillage should be delayed until late spring to maximize cover during the summer until wheat is planted in the fall. Better methods to control grassy weeds are needed so that farmers can plant and establish wheat stands early for fall cover without risking severe weed infestations. Crop growth from early plantings made crosswise to the direction of the prevailing winds can protect the soil against erosion as effectively as a 30 to 40% cover of surface residues. Research is needed on the best ways of strip cropping large blocks of land to reduce field length for wind erosion control. Research also is needed to determine how effectively various forms of surface roughness control erosion and how these features can be achieved with practical tillage and planting systems.

The potential for alternative cropping systems needs to be explored. For example, can overwinter cover crops be used to increase ground cover during fallow and in the following wheat crop? Research also is needed to enhance opportunities and reduce risks for continuous spring cropping. Possibilities include varieties that are more tolerant to drought, low temperature, and the Hessian fly (*Mayetiola destructor* [Say]), and no-till planting systems that can ensure good stands and acceptable weed and disease control.

Tillage for water conservation must be made compatible with tillage for erosion control. A tillage dust mulch is effective for retaining seedzone water (Papendick et al., 1973; Hammel et al., 1981). However, care must be taken so that the tillage system maintains adequate surface cover and roughness to conserve both water and soil.

A more detailed account of farming systems and application of conservation approaches for erosion control and sustainability for the Northwest Wheat Region is given in a recent report "Crop management to reduce erosion and improve soil quality—Northwest" (Papendick and Moldenhauer, 1995). The report is aimed at the user level (farmers, extension agents, NRCS technicians, consultants, etc.) and is based on both research and producer experiences with conservation farming practices to achieve production efficiency, resource protection, and farm profitability in cereal-based cropping systems in the U.S. Pacific Northwest.

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EPA Pesticide Program Adds Partners, Awards Grants

The U.S. Department of Defense has committed to reduce its pesticide use by 50 percent by the end of fiscal year 2000, according to the EPA. The Department said it will examine its properties and determine where use of pesticides is necessary; use safer pest control alternatives whenever possible; and stimulate technology for safer, non-chemical methods of control.

The Department made the announcement when it joined the EPA's Pesticide Environmental Stewardship Program, an effort to reduce pesticide use and related risks to public health in agricultural and non-agricultural settings.

Ten companies and associations have also joined the EPA's program. The companies joined the program as "charter supporters," a role for "groups with significant influence over pest management practices, but not directly engaged in using pesticides," according to the EPA.

The 10 companies are Aqumix Inc., Cloverdale, VA; Bay Area Stormwater Management Agencies Association, San Francisco, CA; Campbell Soup Co., Camden, N.J.; Del Monte Foods, Walnut Creek, CA; Gempler's Inc., Mt. Horeb, WI; General Mills, Minneapolis, MN; Gerber Products Co., Fremont, MI; Glades Crop Care, Inc., Jupiter, FL; National Farm*A*Syst/Home*A*Syst Programs, Madison, WI; and the United States Golf Association, Far Hills, N.J.

As part of the program, the EPA has awarded $740,000 in grants aimed at reducing pesticide use and risk. The first set of grants awarded $240,000 to eight of the program's partners, which are organizations that use pesticides or represent pesticide users. The second set of grants awarded $500,000 to 14 organizations under the EPA Regional Pollution Prevention Initiative Grants.

The partnership grants were awarded to the Cranberry Institute, East Wareham, MA; Golf Course Superintendents Association, Lawrence, KS; Hood River Grower-Shipper Association, Odell, OR; Mint Industry Research Council, Stevenson, WA; Monroe County Community School Corporation, Bloomington, IN; National Potato Council, Englewood, CO; Tennessee Valley Authority, Chattanooga, TN; and Texas Pest Management Association, Austin, TX.

The regional pollution prevention initiative grants were awarded to the University of Massachusetts, Amherst, MA; University of Maryland, College Park, MD (two grants); University of Georgia, Athens, GA; Purdue University, Lafayette, IN; Wisconsin Potato and Vegetable Growers Association, University of Wisconsin, Madison, WI; Texas A&M University, College Station, TX; University of Missouri, Columbia, MO; Colorado State University, Fort Collins, CO; California Beet Growers Association, Stockton, CA; University of Hawaii, Hilo, HI; Community Environmental Council, Santa Barbara, CA; Washington State University, Pullman, WA; and Pacific Coast Cranberry Research Foundation, Ilwaco, WA.

Water conservation practices for sustainable dryland farming systems in the Pacific Northwest

John E. Hammel

Abstract. *Water limits crop production in most of the Pacific Northwest wheat region. Effective tillage and residue management systems are required to conserve precipitation, which provides 60 to 70% of the water for crop needs during the growing season. Annual cropping systems with winter wheat grown in rotation with spring cereals and legumes are used where winter precipitation is sufficient (>450 mm) to recharge the soil profile. A winter wheat-spring cereal-fallow system is common in areas receiving 330 to 450 mm annual precipitation. Where annual precipitation is less than 330 mm, a winter wheat-fallow system is used. Summer fallow is practiced on approximately 60% of the dry-farmed cropland. Frozen soil greatly influences overwinter water storage efficiency and contributes to runoff and erosion. Most erosion occurs on fall-seeded wheat fields. To meet soil and water conservation requirements, various tillage and residue management practices have been developed to account for the diversity and variability in soils and climate across the region. For long-term sustainability, dry-farming practices require both water conservation and residue management that effectively protect the soil. This paper details tillage and residue management practices employed to conserve soil and water and achieve stable crop production in dry-farmed regions of the Pacific Northwest.*

Key words: cropping systems, tillage, winter wheat, dry farming, residue management

Introduction

Effective water conservation practices are important to achieve sustained crop production in the dry-farmed area of the Pacific Northwest because of the low annual precipitation and the predominantly winter rainfall distribution. However, water and wind erosion also are major conservation problems, with water erosion severe on about 72% of the dry-farmed cropland (Council for Agricultural Science and Technology, 1975). Most major erosion occurs from rainfall or snowmelt on frozen soil, and it is not uncommon for a single storm to produce 75% of the annual soil loss (Papendick et al., 1983). Wind erosion is most serious in areas where annual precipitation is less than 300 mm (Leggett et al., 1974). Soil-eroding winds are most frequent in the fall and spring when the soil surface is dry and unprotected (Skidmore and Woodruff, 1968). Therefore, both water conservation and soil and residue management practices are required to achieve sustainable, long-term crop production in the Pacific Northwest dry-farmed region.

Water Conservation

Unlike in continental climates where 60 to 70% of the precipitation occurs during the growing season, in this region most precipitation occurs during the winter. Therefore, maximizing water storage during the winter and minimizing evaporative losses during the summer are fundamental to water conservation for sustained, profitable crop production. Tillage and residue management practices that enhance overwinter storage and suppress evaporative losses are required to provide optimum seed zone moisture for germination and emergence and to ensure adequate stored moisture for crop growth during the normally dry growing season. In the Pacific Northwest, approximately 18.5 kg/ha of winter wheat (*Triticum aestivum* L.) are produced for each millimeter of available water (stored soil water plus spring precipitation) beyond a threshold amount of 100 mm (Fig. 1; Leggett, 1959). Therefore, proper water conservation practices are required to maintain stable yields or achieve substantial gains.

The distribution and amount of precipitation in the Pacific Northwest dry-farmed regions are optimum for recharge during the wet, humid winter months. About 65% of the total annual precipitation occurs

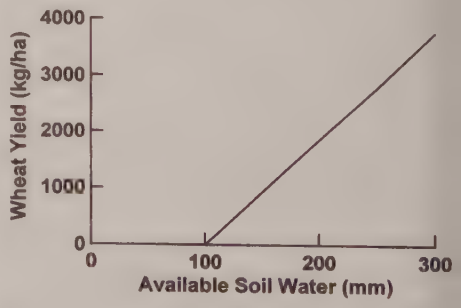

Figure 1. Relationship between available soil water and winter wheat yield in the Pacific Northwest (from Leggett, 1959). Available soil water includes stored soil water plus spring precipitation.

Contribution of the Soil Science Division, Idaho Agricultural Experiment Station, University of Idaho.

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between November and March (Fig. 2). During this period, potential evaporation is sufficiently low to allow downward penetration of water to recharge the subsoil. A factor that can greatly decrease recharge is frozen soil (Zuzel et al., 1982). Infiltration is often drastically reduced and runoff severe when rainfall or snowmelt occurs on frozen soils. Soil loss often is severe also, especially when a thawed layer overlies frozen soil.

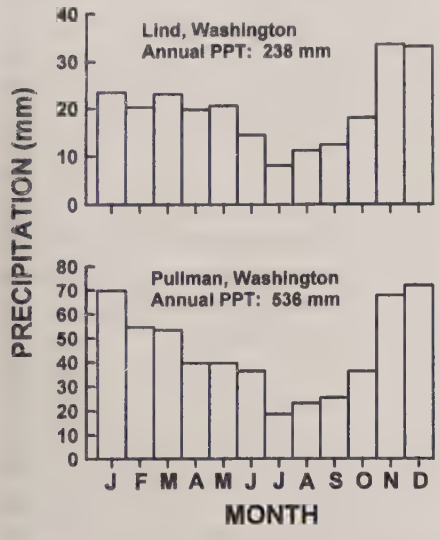

Figure 2. Monthly distributions of precipitation at Lind and Pullman, Washington, which represent summer fallow and annual cropping areas, respectively.

With both summer-fallow and annual cropping systems, an important water conservation practice is fall tillage, particularly on the moderately to steeply sloping croplands (Lindstrom et al., 1974). Tillage enhances surface roughness and macroporosity; if done below normal freezing depths, it also increases surface water retention and infiltration and decreases runoff (Pikul et al., 1992).

Although evaporative demand is low during the recharge period, evaporative losses still can significantly decrease overwinter storage efficiency. Theoretical studies by Cary et al. (1979) and field studies by Pikul et al. (1989) show that freeze-thaw cycles redistribute water upward toward the soil surface. Since 60 to 120 diurnal freeze-thaw cycles are common during a winter season (Hershfield, 1974), substantial upward water movement can occur depending on temperature, residue cover, soil moisture, soil textural and structural characteristics, and drainage. The freeze-thaw mechanism can enhance evaporative losses by maintaining a wet surface, and may increase runoff losses through decreased infiltration.

In areas of low precipitation (<330 mm), tillage and residue management practices are used during summer fallow to reduce evaporation and minimize losses of water stored during the previous winter. A soil mulch produced by tillage is used to conserve the stored water and maintain adequate soil moisture for establishing the wheat stand before winter precipitation. The dry soil mulch restricts liquid water and vapor flow and acts as a thermal barrier to conserve soil water effectively and maintain seedzone moisture during summer fallow (Papendick et al., 1973).

Summer Fallow

Summer fallow is the most common management practice to conserve water in the Pacific Northwest. Approximately 60% of the dry-farmed cropland is in a wheat-summer fallow system (Leggett et al., 1974). Fallow is required for storing enough soil water to insure profitable yields in areas with annual precipitation less than 330 mm. In the intermediate precipitation areas (330–450 mm), summer fallow is practiced, but management practices are modified based on variation in annual precipitation.

A winter wheat-fallow cycle entails approximately a 13-month period between harvest of the wheat crop in July or August and seeding of the next wheat crop during September or October the following year. Water conservation practices are designed to enhance overwinter storage during the winter following harvest and to decrease evaporative losses and maintain moisture in the seed zone during the summer preceding fall seeding of winter wheat.

Overwinter water recharge

Water storage efficiency in the wheat-fallow system is approximately 50% of the total precipitation for the 17 month period from September of the harvest year to March of the crop year (Leggett et al., 1974). During the winter following harvest, soil-water storage generally ranges between 50 and 70% of the precipitation (Massee and Siddoway, 1969; Leggett et al., 1974; Lindstrom, 1974; Ramig and Ekin, 1984). Water storage efficiency is only 10 to 50% of the precipitation during the winter of the crop year following fallow. The main factors that determine recharge efficiency during the fallow and crop winter periods are profile soil-water content, soil surface conditions, occurrence of soil freezing, and frequency and intensity of rainfall or snowmelt. During the winter following harvest, surface residues and a dry profile enhance water infiltration and storage. Recharge during the winter of the crop year is lower because the profile water content is higher, which reduces infiltration.

Fall tillage operations vary throughout the summer fallow areas, primarily because of differences in the amount and type of precipitation, the occurrence and frequency of frozen soil during the winter period, and whether weed control is required. In the northern areas where soils freeze more often, fall tillage is used to shatter the soil surface to improve water infiltration when soils are frozen. Pikul et al. (1992), in a study on a Typic Haploxeroll, observed that the final infiltration rate was 21 mm/hr when the frost depth was 0.12 m and the depth of tillage was 0.2 m, in contrast to no infiltration on untilled soil. However, the benefits of tillage for infiltration were negated when the frost depth was below the depth of tillage.

Overwinter recharge can be improved substantially by maintaining water intake rates by tillage where freezing limits infiltration. Lindstrom et al. (1974) observed that overwinter water storage efficiency on a silt loam (Calciorthidic Haploxeroll) near Lind, Washington, was 87% using fall chiseling, but was only 50% without any fall tillage (Fig. 3). Alternatively, during a mild winter without frozen soil, overwinter storage was about 60% and tillage was of no benefit. In areas where the soil freezes less frequently, fall tillage generally is not beneficial unless a weed or soil compaction problem exists (Papendick and Miller, 1977; Allmaras et al., 1982).

Crop residues following harvest are an important resource in sustaining high water storage efficiencies and controlling soil erosion. Wheat residues following harvest in the dry-farmed region range between 1.5 and 6 t/ha, depending on annual precipitation (Papendick and Miller, 1977). Tillage by itself is not considered a substitute for

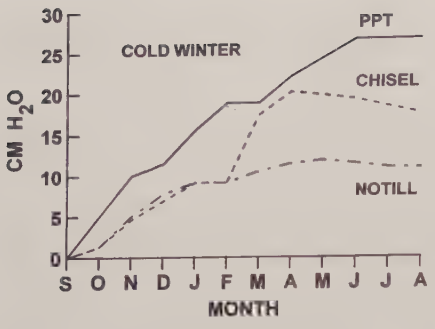

Figure 3. Cumulative precipitation and soil water storage for fall-chiseled and untilled field conditions during a cold winter with frozen soil conditions at Lind, Washington (from Lindstrom et al., 1974)

residue management systems that maintain surface cover; instead, combined tillage and residue management systems are used. Surface residues decrease evaporative losses (Bristow et al., 1986), reduce runoff losses (Massee and Siddoway, 1969), and reduce soil frost by insulating the soil, allowing more water to infiltrate (Pikul et al., 1986),

In areas where there is little benefit from fall tillage because soils freeze less frequently, wheat stubble generally is left standing or maintained on the surface during the winter following harvest. Ramig and Ekin (1984) showed that overwinter storage efficiency (October-March) with standing and flailed stubble was 76% and 73% of the precipitation, respectively, compared with only 57% where stubble was burned. Papendick and Miller (1977) also noted that increasing surface residues during the winter following fallow substantially increases overwinter water storage. In this dry-farmed region, surface residues regardless of form (standing, flailed, or chopped) increase soil water storage compared with non-residue systems. However, standing stubble is the most effective. In northern regions where frequent soil freezing occurs, combining fall tillage with effective residue management also significantly increases overwinter water storage (Saxton et al., 1987).

Evaporation control

Successful fall establishment of winter wheat following summer fallow requires conservation measures that maintain adequate seedzone moisture for germination. Early seeding generally increases yields compared with later seeding (Lindstrom, 1974). Early seeding also provides better crop cover, which protects against wind and water erosion (Cochran et al., 1970).

Timing of initial spring primary tillage is important for conserving stored soil water during the warm, dry summer fallow period. Primary spring tillage is designed to develop a loose soil mulch, control early weed growth, and provide sufficient surface residues for controlling wind and water erosion during the fallow and following crop year. Chisels, sweeps, or disks are mainly used for primary spring tillage. Generally, timing of primary tillage varies from early March to mid-May, depending on elevation and latitude. The first tillage is accomplished as early as possible after the soil surface dries and before weeds become established (Massee and Siddoway, 1969; Oveson and Appleby, 1971; Lindstrom, 1974).

Primary tillage disrupts the continuity of capillary pores with deeper soil layers, which hastens formation of a dry surface layer. This effectively stops liquid water transport to the soil surface; water moves through the dry surface layer primarily as vapor (Willis and Bond, 1971). Evaporative loss is least when the soil is tilled as soon as possible after wetting (Fig. 4). Benefits to water conservation decrease as tillage is delayed, with evaporative loss approaching that of non-tilled soil. However, tilling too early when soils are wet destroys soil structure and compacts the soil. Generally, water loss during fallow is not influenced by the type of implement used for spring tillage (Lindstrom et al., 1974).

Depth of primary tillage varies across the summer fallow region. In general, during the hot, dry fallow period, water in the seedzone is best conserved with a soil mulch that provides resistance to the flow of both water (liquid and vapor) and heat. The thickness of the soil mulch needed to provide these characteristics depends on structure and texture (Papendick and Campbell, 1974). Generally, fine-textured soils, such as silt loams and clays, require a thicker mulch than coarse-textured soils, with their "self-mulching" characteristics. Evaporative loss often is not markedly different between tilled and untilled coarse-textured soils. Papendick et al. (1973) found that a tillage depth of 12 to 16 cm was optimal in silt loam soils of eastern Washington. Usually several rodweedings during the summer are used to control weeds and maintain the loose soil mulch. No increased benefit has been observed with deeper tillage, and deeper tillage sometimes is detrimental to adequate seedzone moisture, consequently reducing fall stand establishment.

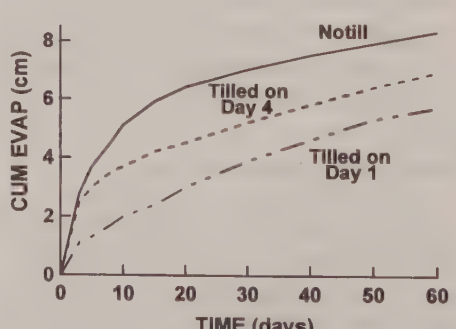

Figure 4. Cumulative soil water evaporation as influenced by timing of tillage after initial wetting (from Willis and Bond, 1971).

A bare mulch, however, can be conducive to high wind and water erosion. Current government-approved conservation programs require tillage systems that provide a certain quantity of surface residues at seeding depending upon land classification and erosion potential. Tillage systems that maintain adequate surface residue can greatly reduce wind and water erosion. These conservation tillage systems also combine the advantages of both tillage and residue in reducing evaporative loss.

Residues reduce evaporation in three ways: by reflecting radiation, which lowers the heat energy at the soil surface; by decreasing heat exchange between the atmosphere and the soil; and by creating a dead air space above the soil surface, which reduces vapor transfer from the soil to the atmosphere. Surface residues are most effective in suppressing evaporation during the first stage of evaporation, that is, when the soil surface is wet. Bond and Willis (1969) showed that increasing the amount of surface residues lowers the rate but extends the duration of first-stage evaporation (Fig. 5). Therefore, even though surface residues reduce first-stage evaporation, cumulative evaporation during extended dry periods may equal the total loss from bare soil. Thus, under dry-farming conditions, the value of surface residues for water conservation is less during the summer, when there is little precipitation. However, surface residues, in combination with a soil mulch,

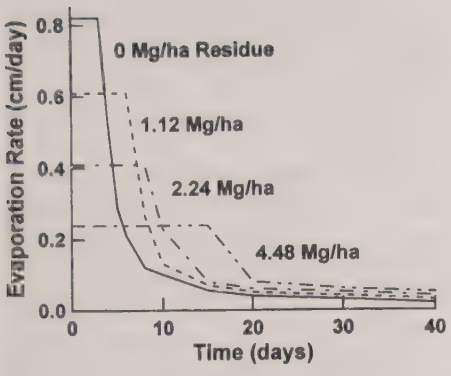

Figure 5. Soil water evaporation rate with time as affected by rates of surface residues (from Bond and Willis, 1969).

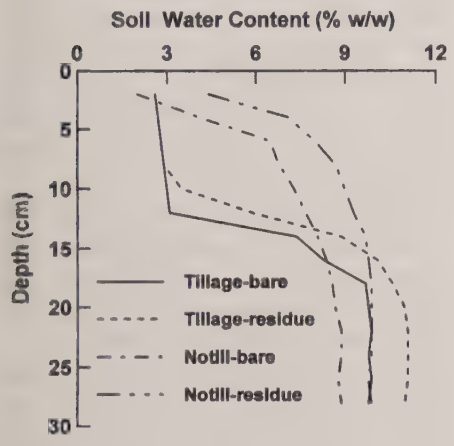

Figure 6. Seedzone water content at fall planting as affected by tillage and surface residue (Papendick and Hammel, unpublished data).

result in higher seedzone moisture at seeding compared with a soil mulch alone (Fig. 6). The greatest value of surface residues during the summer in dry-farmed areas is in the control of wind and water erosion.

Surface residues are most effective in conserving water in the Pacific Northwest during the wet, cool winters. Bristow et al. (1986), using computer simulation, showed that during the winter months when the soil surface is wet, evaporation is lower from residue-covered than from bare soil, resulting in greater overwinter water storage (Fig. 7). However, cumulative evaporation during the summer months is greater with residue-covered soils because first-stage evaporation is extended; evaporation is lower from bare soil once the soil surface has dried. In a field study at Lind, Washington (240 mm annual precipitation), Papendick and Miller (1977) observed that 0, 5, and 11 t/ha of surface residues resulted in water storage efficiencies of 48, 66, and 81%, respectively, during the low evaporative demand period between September and March. Although oversummer evaporative water losses for the residue treatments were greater, net fallow storage with surface residues of 0, 5, and 11 t/ha were 7.3, 9.3, and 11.6 cm, respectively. Thus, while research shows that residues are effective in reducing evaporative losses during periods of frequent precipitation, surface residues are not as effective in conserving water in dry-farmed areas during extended dry periods such as the long summer fallow period.

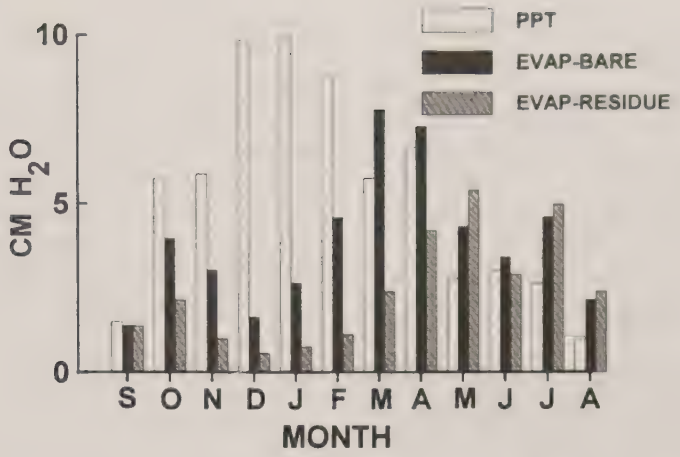

Figure 7. Monthly precipitation and simulated evaporation for bare and residue covered soil conditions at Pullman, Washington (from Bristow et al., 1986).

Chemical fallow

While there is interest in the use of herbicides to control weeds without any tillage during summer fallow to improve erosion control and to conserve energy, chemical fallow has been used with limited success in the Pacific Northwest region. Without a soil mulch, deeper drying occurs during the summer fallow period, so that seedzone moisture adequate for germination and emergence occurs at greater depth (Hammel et al., 1981). Ovenson and Appleby (1971) and Lindstrom et al. (1974) observed that although oversummer water loss was similar from chemical and soil mulch fallow, less moisture was retained in the seedzone of silt loam soils with chemical fallow. Inadequate seedzone moisture delays germination of winter wheat until fall precipitation, and can significantly lower yield (Lindstrom, 1974).

Herbicides are currently being substituted for early spring tillage during fallow under reduced tillage systems. With the use of effective non-selective herbicides, primary tillage often is delayed until mid-May without undue soil moisture loss. Delayed primary spring tillage conserves surface residue and reduces pulverization of clods, thus decreasing the potential wind erosion hazard. Herbicides do reduce the number of tillage operations and conserve energy during the summer fallow season. However, it is generally accepted that soils should be tilled, in conjunction with good residue management practices, before June during the fallow period to insure successful establishment of a fall crop where annual precipitation is less than 330 mm.

Annual Cropping

Crops are grown without fallow where annual precipitation exceeds 450 mm because precipitation during the winter is sufficient to recharge the soil profile. However, soil and water conservation practices are needed in these areas to maintain infiltration, control erosion, and optimize crop yields. In the annual cropping regions, winter wheat is grown in 2- or 3-year rotations with spring crops.

Government-mandated conservation programs require residue cover on 30% of the soil surface following seeding of winter wheat. Surface residues following winter wheat harvest typically range between 3 and 6 t/ha (Papendick and Miller, 1977), sometimes

higher. Heavy surface or shallow-incorporated residues can cause poor crop stands, stunted growth, and low yields. These problems result from several factors, including: phytotoxicity from residue decomposition; favorable conditions for pathogens; reduced soil fertility; and poor seed-soil contact at seeding (Elliott et al., 1987).

Conservation tillage systems

In annually cropped areas where the soil freezes, fall tillage improves infiltration and reduces runoff and erosion during the winter and early spring. Before the conservation compliance requirements of the Food Security Act of 1985, winter wheat stubble was moldboard plowed following harvest to bury approximately 90% of the stubble. The rough-plowed surface effectively controlled erosion and maximized water infiltration and storage during the winter following harvest. However, the surface residues that remained were insufficient for adequate erosion control during the remainder of the rotation, which includes low residue producing crops such as peas (*Pisum sativum* L.) and lentils (*Lens culinaris* Medik). Best management practices adopted since the late 1980s include chiseling or other tillage that does not completely bury surface residues. These practices include single-pass till-plant systems and no-till. Surface residue management systems increase water storage by decreasing evaporative losses (Pikul and Allmaras, 1985; Bristow et al., 1986), reducing runoff (Papendick and Miller, 1977; Ramig and Ekin, 1984), decreasing depth of frozen soil (Pikul et al., 1986) and improving snow entrapment (Massee and McKay, 1979). Reduced tillage systems currently used in the annual cropping region that maintain higher levels of surface residues have yields equal to or greater than those of past conventional practices (Young et al., 1994; Hammel, 1995).

Annual cropping on shallow soils

About 400,000 ha of cultivated soils in the dry-farmed cropping region are only 50 to 100 cm deep, or are coarse-textured and have profile water-holding capacities less than 160 mm (Ramig, 1987). Annual precipitation in this region (>200 mm) is sufficient to fill the soil profile to capacity every winter. A winter wheat-fallow system to conserve water under these conditions does not benefit crop production. Also, severe water erosion can occur in a fallow system during the crop winter because the profile before the wet period is essentially fully recharged, which limits water intake.

Because of soil conservation and water use considerations, these shallow soils generally are cropped annually. Annually cropped wheat, including spring wheat, yields 60 to 70% as much as winter wheat following fallow (Ramig, 1987). Therefore, over the two years, production on shallow soils generally is higher with annual cropping than with wheat-fallow. Deeper soils (>120 cm) in the same rainfall zones are managed with a wheat-fallow system to achieve stable yields.

Summary

Sustainable crop production in the Pacific Northwest dry-farmed areas relies heavily on tillage and residue management systems to conserve water. Stable, sustainable yields cannot be achieved without adequate water conservation techniques. Frozen soil can reduce infiltration markedly, which decreases overwinter profile water storage and can cause severe soil erosion. Uncurbed evaporation losses throughout the year can greatly limit yields, particularly with summer fallow.

In both summer-fallowed and annually cropped regions where soil freezes frequently, fall tillage is used to increase surface macroporosity and to provide open channels to below the frost depth. This enhances infiltration throughout the winter and insures better water intake during rapid snowmelt and rainfall when the soil is frozen. Fall tillage enhances overwinter water recharge under these conditions, whereas in areas where soil freezes infrequently, it does not improve water storage efficiency.

In the dry-farmed regions receiving less than 330 mm annual precipitation, a winter wheat-fallow system is used to reduce the risk of uneconomical yields. Successful establishment of winter wheat following summer fallow is feasible only when proper management has suppressed evaporative loss. During the dry summer fallow, tillage is used to develop and maintain a soil mulch that restricts the flow of water, as both liquid and vapor. The tillage mulch effectively conserves stored soil water and maintains adequate seedzone moisture for fall establishment of winter wheat. However, the soil mulch can lead to high wind and water erosion.

In the Pacific Northwest dry-farmed region, tillage by itself is not considered a substitute for proper residue management. Crop residues following harvest are important for conserving water and controlling erosion. Under conservation programs implemented since 1985, shallow subsurface tillage systems that maintain residues on the surface have substantially reduced wind and water erosion in the region. Surface residues are effective in decreasing evaporative water loss and trapping snow during the winter, and therefore increase overwinter recharge. While surface residues are much less effective in suppressing evaporative losses in dry-farmed areas during extended dry periods, residues provide substantial control of wind and water erosion during the fallow.

Before conservation tillage systems came into use in the Pacific Northwest, water conservation frequently was achieved only through tillage. This helped to stabilize yields, but at a high cost to the soil resource. Poor use of surface residues and intensive tillage contributed to extensive wind and water erosion. Continued use of these practices would have caused yields to decline over time and required greater agrichemical inputs. To meet soil and water conservation needs, site-specific tillage and residue management systems were developed to account for the diversity and variability of soils and climate across the Pacific Northwest. Common to all these production systems is that both water conservation and effective residue management to protect the soil are required for long-term sustainable production.

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Millions Drank Water Polluted With Pesticides, Says Report

More than 45 million Americans were served drinking water during 1994–1995 that was polluted with unsafe levels of pesticides, toxic chemicals, parasites, lead, and other chemicals, according to a recent report by the Natural Resources Defense Council, the Environmental Working Group, and the Environmental Information Center.

In 1994–1995, 471,700 people drank water from 588 water supplies that violated the EPA's standard for nitrate contamination, the principal cause of which is overuse of nitrogen fertilizer, the report said.

Just Add Water is $20 plus $3 postage and handling from EWG, 1718 Connecticut Ave., NW, #600, Washington, D.C. 20009; (202) 667-6982. The report is available on the World Wide Web at http://www.ewg.org

Agricultural wind erosion and air quality impacts: A comprehensive research program

Keith E. Saxton

Abstract. *With the passage of the 1990 Clean Air Act came the responsibility to monitor and control particulates in the size range 10 μm and smaller (PM_{10}). Many urban areas, particularly in the western U.S., have experienced concentrations of fugitive dust particulates from upwind sources that exceed the federal health standards. Often a significant amount of this material is generated upwind on agricultural fields, and then is entrained and transported in the regional air mass, thus degrading the air quality in downwind urban regions. Current technology cannot adequately quantify the fugitive dust emitted and transported from agricultural sources, nor specify adequate control methods. A comprehensive research plan recently was developed and initiated for the Columbia Plateau of eastern Washington State that involves multiple disciplines and several state and federal agencies. This research has several components: characterizing the soil, vegetation and climate in a region of 136,000 km^2; developing wind erosion and fugitive dust emission relationships for individual farm fields; developing and applying transport-dispersion-deposition models of the region; selecting and testing farm-level control strategies; and providing public information to both the urban and farm communities for understanding the problem and developing management plans. Simultaneous receptor analyses and public health research combine to make this a comprehensive regional research effort on fugitive dust emissions and impacts.*

Key words: wind erosion, air quality, conservation, dryland farming, cereal, dispersion models, dust, particulate, PM_{10}

Introduction

Dryland agriculture is the major crop production system of the world. In many dryland farming regions, wind erosion constantly threatens to deplete the soil resource by completely or selectively removing fines, the soil component most active in plant production. Almost all soils have some susceptibility to high winds, whatever the topography. The broad, undulating dryland regions of the U.S. Pacific Northwest have been particularly vulnerable in recent years because of a prolonged drought, but similar episodes occurred previously (Cameron, 1931).

Poor air quality has become a major issue across the U.S. and the world, with fugitive dust particulates from wind erosion increasingly being recognized as a contributor. Considerable air quality legislation has been passed and implemented in the U.S. during recent years. The U.S. Environmental Protection Agency (EPA) is implementing a new program to meet the National Ambient Air Quality Standard for particulate matter, which was approved by the federal government through the 1990 Clean Air Act Amendments. This national legislation has resulted in additional state and local legislation, such as the 1992 Washington State Clean Air Act, which includes regulations on burning, dust, and other airborne particulate sources from industry, forestry and agriculture. Most of this recent federal and state legislation has focused on very fine particulate material less than 10 μm in diameter (PM_{10}), the size that is most injurious to human health (Glen and Craft, 1986).

Many urban areas have been designated as "non-attainment" areas in recent years because of concentrations of fugitive dust that repeatedly exceeded the federal health standards. These areas are concentrated in the western U.S., where dry soil conditions and limited vegetation in upwind regions cause wind erosion and fugitive dust emissions.

Wind erosion research over the past 50 years has provided much knowledge and data for action agencies to advise farmers about control strategies. This has helped greatly in protecting our farmlands from a repeat of the "Dust Bowl" of the 1930s. The emission of PM_{10} material, although thought to be closely related to wind erosion, is not predictable with currently available data or models. As a result, it also is not clear how to control PM_{10} emissions from agricultural regions.

To address the problem of erosion and PM_{10} fugitive dust for a study region in the Pacific Northwest, an integrated research project has been planned and initiated by a multidisciplinary, multi-agency team of scientists from the U.S. Department of Agriculture, universities, and regulatory agencies. Current policies will be combined with the research results to develop implementation plans involving predictions of wind erosion, air quality, and effectiveness of prescribed remedial measures.

Background

Wind erosion has been studied and described for many years. Many publications

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describe the ravages of wind erosion as observed from the "Dust Bowl" of the 1930s through today. Climatic extremes and human activities are most often the cause of accelerated erosion above the normal geological level. The results are always the same: the eroding soil is depleted as a resource, plants and animals are harmed, and the airborne soil is deposited where it is not wanted, becoming a contaminant and health risk.

Wind erosion can have severe on-site and off-site economic consequences (Piper, 1989a). Particulates with aerodynamic diameter less than 10 μm (PM_{10}) generated during wind erosion have been implicated as a health problem for urban areas (Jutze and Axetell, 1974; U.S. Environmental Protection Agency, 1987). This off-site hazard from wind erosion is particularly severe in parts of the western U.S. where urban areas are downwind from dry, highly erodible farm and range lands (Piper, 1989b).

Wind erosion processes and mechanics have been extensively described (Chepil and Woodruff, 1963). More recently, the mathematics and physical principles have been adapted for modern computer analysis, beginning with simple, single-field models and going on to more comprehensive models and total systems (Hagen, 1991). These will result in prediction systems that will replace older handbook methods (e.g., U.S. Dept. of Agriculture, 1968).

For many years, wind erosion has been successfully predicted using an equation that in simplified form can be written as:

$$E = f(I,K,C,L,V)$$

where:

E = estimated potential annual soil loss, tons/acre
I = soil erodibility factor
K = soil surface roughness factor
C = climatic wind energy and soil moisture factor
L = field length factor
V = vegetative cover factor

This equation represents wind erosion as resulting from interactions between wind forces and field surface conditions (soil characteristics, surface roughness, vegetative cover and the upwind erodible field length in the direction of wind travel). As currently used, it estimates average annual soil mass that is transported across the downwind edge of a field. However, the loss is calculated using a complex procedure that involves many additional charts, graphs and other tools.

Predictions using this equation include all categories of soil transport mechanisms: creep (particles rolling along the surface); saltation (particles bouncing across the soil surface); and suspension (particles that remain in the air after the wind velocity falls below the value required to move surface particles). The smallest and lightest particles become suspended, including PM_{10} material. There is no clear relation between total suspended particles and the PM_{10} portion, but it is undoubtedly a function of soil particle distribution of the eroding field surface, amount of soil aggregate degradation, wind velocity and turbulent diffusion, and vegetative interactions. Only through simultaneous measurements of wind erosion and PM_{10} fluxes at standardized wind erosion verification sites can we determine the relations between total suspended material, PM_{10} fraction, and associated variables. Moreover, these relations probably vary among regions.

Detailed methods to predict wind erosion require accurate specifications of the wind velocities and profiles and of the soils and surfaces over which these winds occur. Wind profiles and movements over land have been well documented for many farmed conditions, and soil erodibility has been described and indexed for many U.S. soils (Lyles and Tatarko, 1988; Abtew et al., 1989). Soil texture, organic matter, moisture and air humidity all affect wind erosion; in turn, some of these variables themselves are altered by erosion. Vegetation plays an important role in the wind-surface interaction, and the micro-relief of the soil surfaces can be very influential.

Both the theory and the measurement of wind erosion present difficult problems. Recent developments have provided methods and instruments capable of enhanced in-field measurements that cover the range of values needed to verify the prediction models. These data, coupled with real-time weather measurements or stochastic weather generators, allow wind erosion to be documented and predicted with increased accuracy. Wind tunnel studies have defined some key parameters.

Wind erosion control has focused on preserving or altering the soil surface and vegetative cover, such as by using soil ridging or soil stabilization materials (Fryrear, 1984). Vegetative cover has been one of the most effective measures; many forms have been used, with varying degrees of success (Skidmore and Nelson, 1992). Various vegetative wind barriers also have been evaluated in combination with conservation practices, such as strip cropping, wherever these are practical in particular crop rotations and farming systems (Borrelli et al., 1989).

Recent research, largely on occupational health risks, has strongly implicated airborne PM_{10} particles as the most serious for causing pneumoconiosis. These very small particles, acting similarly to aerosols, most readily pass through the breathing system and get absorbed into the lung tissue. Inorganic and organic particulates plus living microorganism all may be included. The microbial materials can have health consequences at concentrations as low as one part per trillion because they have life and the capacity to grow. Examples of pneumoconiosis are silicosis, asthma, and rhinitis; associated inhaled diseases include anthrax, histoplasmosis, and brucellosis.

The processes that generate and entrain aerosols and very fine particulates during wind erosion are not well understood. Clay and fine silts are in the PM_{10} size range, and if acting individually could become airborne and suspended. However, in most soils these soil particles are a component of much larger aggregates. It is believed that the dominant mechanism of PM_{10} production by soil erosion is "sandblasting" of the aggregate surfaces. If so, this is a dynamic part of the wind erosion process and is likely to be a function of the parent soil's particle size distribution, amount and form of organic matter, moisture, and wind interactions, but these relationships have not yet been determined.

The Columbia Plateau Region

In the Columbia Plateau in the Pacific Northwest, millions of hectares of cropland and grazing lands receive low rainfall and are highly susceptible to wind erosion. The complete 340×400 km study region is shown in Fig. 1, with county boundaries and land use categories. The eastern two tiers of counties are in Idaho, the southern tier is in Oregon, and the remainder in southeast Washington. The prevailing wind direction is from the southwest to the northeast,

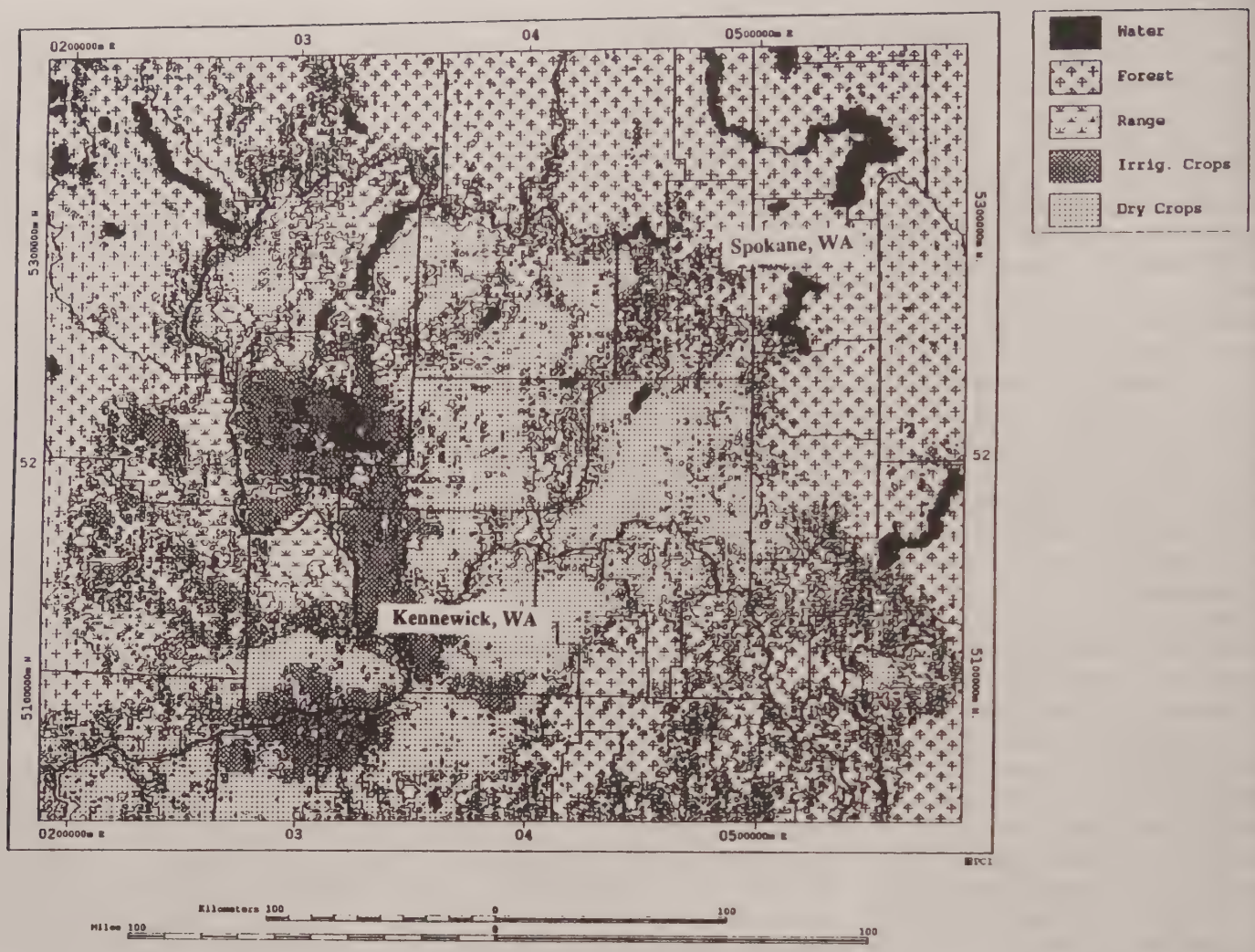

Figure 1. The Columbia Plateau wind erosion and fugitive dust study region with major land use categories.

putting Spokane and Kennewick downwind from dry farmland.

Much of this region is arid or semiarid, but significant portions have been cultivated and are now farmed either as dryland or irrigated. These lands usually are protected from wind erosion by vegetation when precipitation is normal or above normal. However, when precipitation is below normal for several years, as happened recently, there is a significant risk of wind erosion. Irrigated lands also are susceptible, particularly during spring and fall, when there is limited vegetation or residues and increased probability of high winds.

Recent episodes of blowing soil in this region have closed roads, caused auto accidents, closed schools, caused respiratory problems in metropolitan areas, and generally degraded the urban environment. Several cities such as Spokane and Richland, Washington, have been or may soon be classified by EPA as "non-attainment" because of high concentrations of PM_{10} particulates. This classification and associated remedial measures may result in extra controls on industry emissions, loss of new industry, and exodus of retirees and tourists.

Particulate concentration data indicative of air quality in the West are shown in Fig. 2 for Spokane and Kennewick, Washington. For this example year of 1992, Spokane had five occurrences and Kennewick two occurrences that exceeded the allowable average daily limit of 150 $\mu g/m^3$, all during August through October, when wind erosion was observed in the upwind regions. Maximums that year were 600-800 $\mu g/m^3$; other years have had values up to 1600 $\mu g/m^3$, all on days of observed wind erosion.

For these two cities during the four months August-November, 1992, Fig. 3 shows the relationship between the measured urban area PM_{10} concentrations and average daily wind speed at an upwind location within the respective windshed. Maximum wind speeds for short durations, such as 15 minutes, often are two to five times the daily average, and gusts during these events are even higher. These examples demonstrate that there is a high correlation between degraded urban air quality and the occurrence of upwind erosion.

Many soils of the Pacific Northwest and throughout the western U.S. are very susceptible to wind erosion because of their origin. Most are a mixture of loess (windblown silt), volcanic ash, and glacial outwash, and many are moderately sandy with some very fine particulates but very low

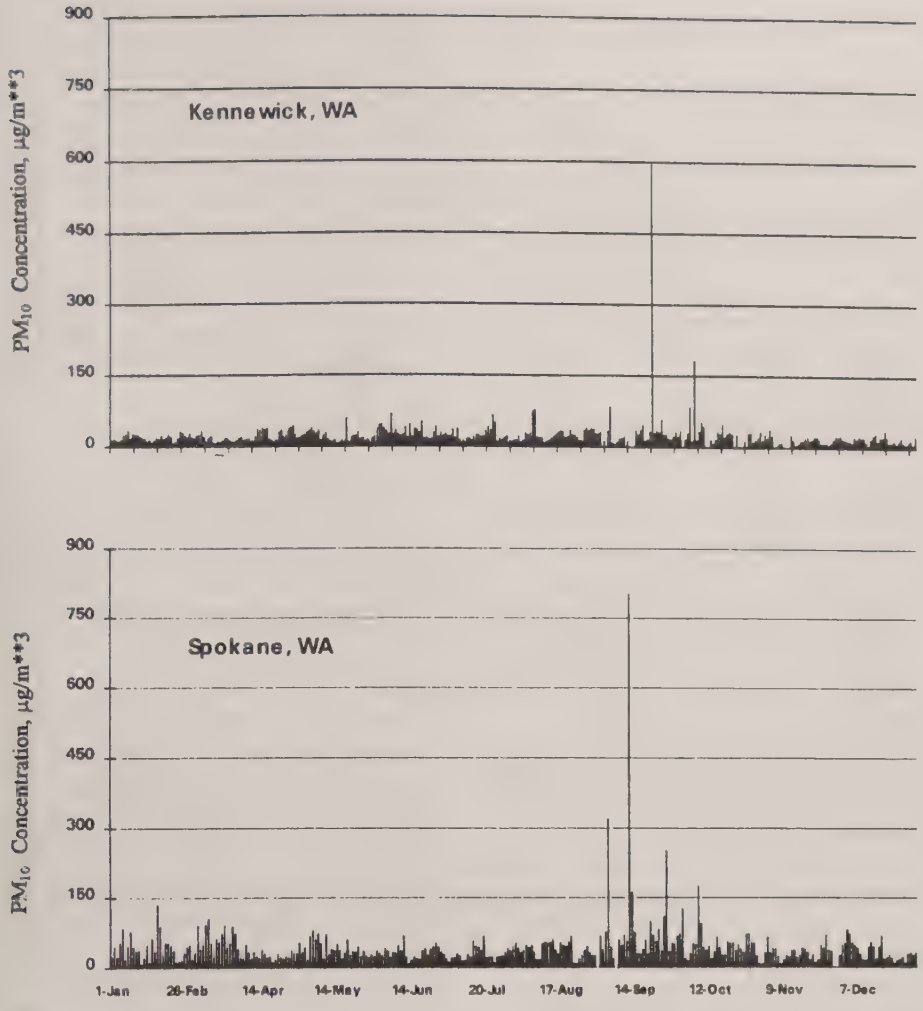

Figure 2. Example fugitive dust concentrations for two Northwest cities subject to wind-blown fugitive dust.

organic matter (less than 0.5%). This absence of binding agents (clay and organic matter) makes them very poor for the formation of aggregates, clods or stable microtopography. Preliminary measurements suggest that as much as 4.0% of the surface soil material in the Pacific Northwest may freely exist in the PM_{10} range, compared with perhaps 0.25% in midwestern U.S. soils, where aggregation is much more prevalent.

The relationship between emitted PM_{10} particulates and wind erosion on agricultural lands is almost unknown. There is circumstantial evidence of a correlation, such as dust clouds several thousand feet high, miles downwind from eroding fields, but the data are inadequate to verify or quantify these effects (Matsumura et al., 1992). Better data must be obtained to avoid urban health and economic problems and to establish reasonable policies and control strategies.

Many tillage practices, such as dust-mulch fallow, are not generally compatible with good wind erosion control. Little residue remains on the soil surface by midsummer, and the soils become highly pulverized by multiple tillage operations during the fallow period to control weeds and preserve seedzone water for fall planting. This is particularly evident during periods of below-normal precipitation, when less vegetation is produced on crop and pasture land. Tillage to develop soil surface corrugations, roughening, or clods generally has not been successful because the soils are very low in organic matter and are poorly aggregated. New fallowing methods and alternative cropping systems will need to be devised, tested and applied to reduce wind erosion and PM_{10} emissions from these fields.

Farmers and conservationists have been pressured into taking emergency remedial actions by local authorities and citizens during a series of erosion events. They often have been unable to develop long-term farming methods that prevent wind erosion. Some methods, such as importing straw residue, tillage to increase surface roughness, and reseeding of killed crops, have been tried at considerable expense, but with limited effectiveness. Other methods need to be devised and tested.

A Research Plan

Through a series of workshops, a multidisciplinary research plan has been designed that will assess the downwind impact of farmland wind erosion within the Columbia Plateau, a region of some 65,000-80,000 km^2 bounded approximately by the Blue Mountains on the south, the Columbia River and Cascade mountains on the west and north, and the Rocky Mountains on the east. The objectives of this plan are shown in Table 1. Each objective contains multiple tasks to be accomplished by one or more scientists that will be done in sequence over three to four years as funding is available.

The first task is to obtain soil, climate, vegetation and farming practice data from both the literature and from measurements made on a 1×1 km grid (Objective 1). These data sets will be managed and coordinated by a geographical information system. The broad land-use categories have been defined from 1990 biweekly composites of National Oceanic and Atmospheric Administration, Advanced Very High Resolution Radiometer, and satellite data analyzed as Normalized Difference Vegetative Index. Data also have been developed on digital elevation, political boundaries, soil organic matter, and meteorology. Following calibration of an appropriate wind erosion model, these mapped regional data will be used as input to show spatial patterns of wind erosion susceptibility and subsequently a spatially distributed PM_{10} emission inventory. Long-term climatic data will determine event probabilities and detailed wind fields for analysis of individual events.

Three sites have been instrumented in highly erodible areas to simultaneously measure wind erosion and PM_{10} emissions (Objective 2). The instrument package includes techniques developed by the Wind Erosion Protection System (WEPS) team so that the data will be compatible and can

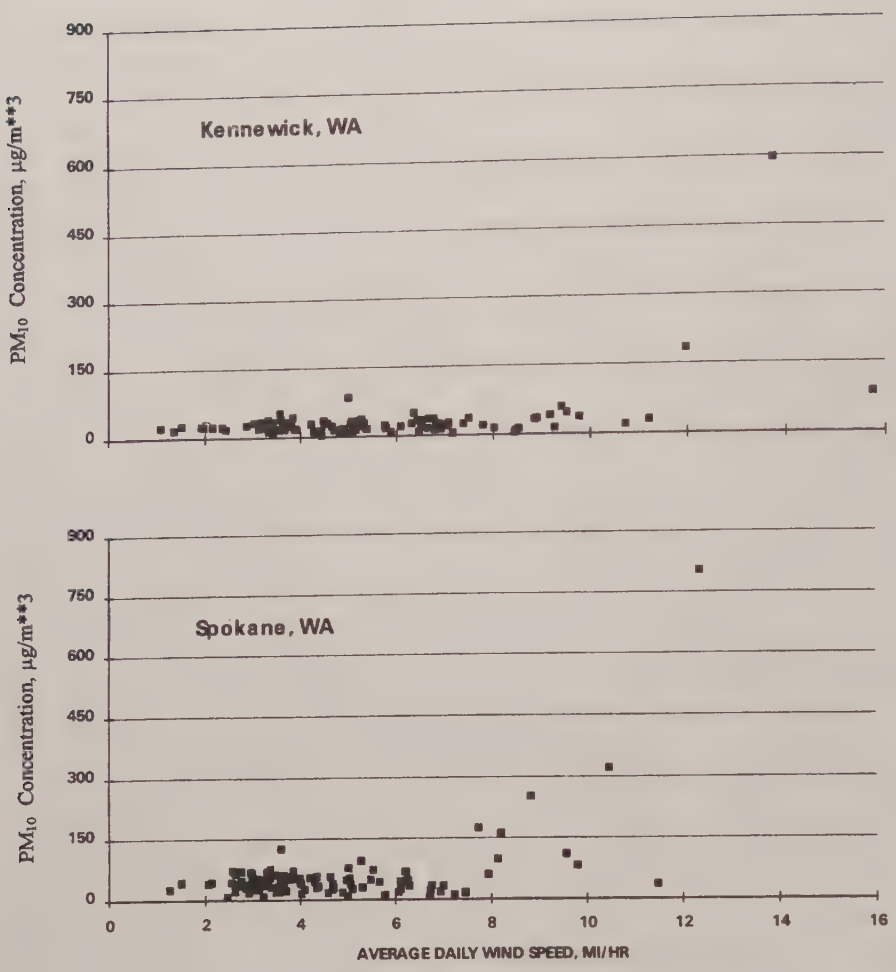

Figure 3. Relationship between fugitive dust concentrations and upwind air velocities. Exceedance days are those greater than 150 µg/m^3.

provide calibration and verification of the revised wind erosion equation and the WEPS model (Hagen, 1991). These instruments include a complete weather station with wind velocity measurements at four heights, an electronic data logger, and 15 masts placed in a pattern to measure soil movement for dominant wind directions. Each mast supports five dust samplers up to a height of 1.5 m. To compare suspended wind erosion material with emitted PM_{10} particulates, both high volume and portable, low volume PM_{10} samplers are included at the field sites, plus PM_{10} measurements upwind and downwind along the prevalent wind direction to estimate off-site influences.

Many variables determine the amount of wind erosion and the associated PM_{10} emissions from agricultural land. It is impractical to establish intensive wind erosion measurements on enough sites to cover all combinations of variables. Therefore, a portable wind tunnel has been designed and constructed to make measurements on many sites with highly variable conditions that will be carefully described and documented at the time of the test. This wind tunnel is approximately 11 m long, with a 6 m test section, and is 1.2 m high by 1.0 m wide. It is mounted on a trailer with an engine. The combined data from these tests will provide the parameter values for a wide range of field conditions that might occur or that might be created to control wind erosion. For example, improved tillage and vegetation management through new farming practices will be established and evaluated for their impact on wind erosion and particulate emissions.

The estimates of emitted PM_{10} particulates from agricultural regions will provide input into a regional air transport-dispersion-deposition model (Objectives 3 & 4). The CALMET and CALGRID models are being applied initially (Scire et al., 1990). Modifications have been made to represent the nonpoint-source emissions from agricultural lands. The wind erosion and air transport modeling will show which agricultural lands within the region are most susceptible to wind erosion and are most likely to affect downwind urban regions.

Wind erosion on agricultural fields is most often controlled by tillage, vegetation, residues, and conservation practices such as strip cropping. The dryland farming areas of the Columbia Plateau that are most susceptible to wind erosion often are in large (100-400 ha) fields, and commonly in a two-year rotation of winter wheat (*Triticum aestivum*) and fallow. The fallow period often has very little residue cover, with the soil surface becoming extremely powdery from frequent tillage with sweeps and rod weeders. Almost no strip cropping is practiced in the Columbia Plateau.

Improved cropping systems and farming methods must be developed to reduce erosion and PM_{10} emissions (Objective 5). Particular emphasis will be on improved fallowing practices using methods such as reduced tillage with total or partial chemical weed control, and various residue management strategies to protect the soil surface. New tillage implements or revised use of existing implements will be an integral component. Promising practices will be evaluated for their effectiveness in controlling wind erosion and for their agronomic and economic suitability.

Wind erosion estimates using current prediction techniques often have not identified much of the Columbia Plateau's farmland as "highly erodible lands" (HEL). Thus, they are not eligible for conservation assistance, such as through the Conservation Reserve Program. Yet, because many of these fields have had significant wind erosion, the prediction methods may have significant inaccuracies, most likely because of limited data on the input variables such as the soil erodibility and wind velocities. These inadequacies will be corrected by the results of the proposed research, which will better determine which lands are eligible for assistance to implement improved conservation practices (Objective 6).

It is well established that wind erosion in the Columbia Plateau has been common throughout geologic time. Many of the major soils in the study region have developed

Table 1. Objectives of the Pacific Northwest Columbia Plateau Wind Erosion/Air Quality Project.

1. Develop low and moderate resolution base data for the Columbia Plateau in GIS format necessary to describe major input variables such as climate, soil, vegetation and farming practices required to estimate agricultural wind erosion and PM_{10} particulate emissions.
2. Establish the theory, quantification, and verification of simultaneous wind erosion and PM_{10} fluxes on agricultural lands in the Columbia Plateau with data from several intensively instrumented agricultural field sites and a portable wind tunnel for calibration of the USDA National Wind Erosion Prediction System.
3. Obtain, test and evaluate air mass transport-dispersion-deposition models suitable to predict PM_{10} concentrations over the Columbia Plateau from spatially distributed agricultural emission sources.
4. Develop a PM_{10} air quality inventory for wind erosion events in the Columbia Plateau region and the probable urban impacts, utilizing the results and methods of objectives 1, 2 and 3.
5. Identify and test wind erosion and PM_{10} emission control methods of alternative cropping systems (tillage, crops, rotation, weed control, etc.), and evaluate their effectiveness through descriptive measurements and portable wind tunnel tests.
6. Use data developed in objectives 1, 2 and 3 to reclassify suspect areas appropriately as highly erodible lands (HEL) for control through Food Security Act of 1985 (FSA) assistance and develop a strategy with USDA-SCS to set FSA criteria for on-farm compliance and assistance.
7. Determine the relative impact of human activity on suspended dust and PM_{10} emission rates in the Columbia Plateau by determining erosion rates for nonanthropogenic and anthropogenic areas on a regional basis and estimating pre-human erosion rates for soils during high wind events.
8. Develop an awareness and increased understanding by both rural and urban populations in the Columbia Plateau through educational materials, programs and news media about wind erosion, PM_{10} particulate emissions and current and prospective control methods.

from loessial, wind-blown materials deposited over many thousands of years. To arrive at reasonable control policies for a specific area, it is important to assess the impacts of human activity compared with what occurred naturally over geologic time. The relative magnitude of natural and human impacts will be established through regional geological studies and analysis of sample filters within the study areas (Objective 7).

Scientific facts about wind erosion and air quality will be developed and disseminated to both rural and urban populations, and efforts will be made to increase public awareness of the problem so that the public readily participates and cooperates in implementing control measures. Although degraded air quality has commonly been recognized as unhealthful, many people need additional information on the health hazards that have been identified more recently and on common particulate sources, especially agricultural land. Through the participation of agencies such as the Cooperative Extension Service and the Natural Resources Conservation Service, these findings will be publicized with both a scientific and policy perspective (Objective 8).

Conclusions

Air quality monitoring in recent years has shown PM_{10} concentrations in many urban areas in the western U.S. that exceed health standards. There is strong circumstantial evidence that many of these occurrences are associated with wind erosion and particulate emissions from upwind agricultural lands. However, there is very limited technical capability to quantify these erosion emissions and their transport to downwind urban areas. Until this capability is adequate, there will be little advancement toward effective and economical control of the impacts of agricultural wind erosion on urban air quality. A comprehensive, multidisciplinary and multi-agency plan has been designed and initiated in the Columbia Plateau of eastern Washington that will provide information and knowledge both to protect the soil resource and to reduce the degradation of air quality from wind erosion and emitted fine dust particulates.

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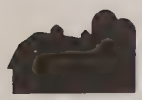

INSTITUTE NEWS

Institute Report Looks at Industrial Reorganization of Agriculture

The Industrial Reorganization of U.S. Agriculture: An Overview and Background Report, recently published by the Wallace Institute, examines the industrial reorganization of U.S. agriculture, and how that reorganization affects elements of sustainability. Author Rick Welsh draws from the literature in law, sociology, economics and political science, and attempts to illustrate areas for future inquiry.

The report's chapters explore what agricultural industrialization is, why agriculture is industrializing, what the consequences of this industrialization are, and the results of four focus group interviews. Copies of the report are $5.50 from the Wallace Institute, 9200 Edmonston Road, #117, Greenbelt, MD 20770; (301) 441-8777.

David Ervin Named Director of Wallace Institute's Policy Studies Program

Dr. David E. Ervin, Professor in the Department of Agricultural and Resource Economics at Oregon State University, has become the Director of the Wallace Institute's Policy Studies Program. He was head of Oregon State University's Department of Agricultural and Resource Economics from 1991 through 1993, and had been a visiting senior analyst at the Office of Technology Assessment's Environment Program from 1994 to 1995. He also served as Chief of the Resource Policy Branch, Resources and Technology Division, at the USDA's Economic Research Service from 1988–1991.

Ervin's work has focused on natural resource and environmental policy related to agriculture and rural areas. The Wallace Institute's Policy Studies Program responds to the need for sound facts and information on the sustainability of agriculture to help inform the national policymaking process. Ervin succeeds Katherine R. Smith, who became Director of the ERS's Commercial Agriculture Division.

Cass Peterson, Ward Sinclair Win Sustainable Ag Leadership Award

Organic farmer Cass Peterson and her late husband Ward Sinclair have been honored with the fourth annual Sustainable Agriculture Leadership Award from the Pennsylvania Association for Sustainable Agriculture. Peterson is a member of the Wallace Institute's Board of Directors; Sinclair had served on the Board for five years. The award was given for the couple's "outstanding leadership and support of sustainable agriculture in Pennsylvania and the United States, and in recognition of their untiring efforts to educate wannabe farmers, to create new opportunities for all local and organic producers."

PASA has also established the Ward Sinclair Endowment Fund to help finance future programs for new and beginning farmers. For details or to make donations, contact PASA at P.O. Box 419, Millheim, PA 16854.

Members of Wallace Institute's President's Council Named

Anne K. Vidaver, President of the Wallace Institute, has announced the members of the 1996–1997 President's Council, formed six years ago to provide guidance and support for Wallace Institute activities in promoting a more sustainable agricultural system in the United States and abroad.

Members are: Dr. Charles Benbrook, Benbrook Consulting Services; Norman A. Berg, Washington Representative, Soil and Water Conservation Society; Hon. George E. Brown, Jr., U.S. House of Representatives; Ron Ellermeier, farmer, Glenvil, NE; Robert Gray, Resource Management Consultants; Ralph Grossi, President, American Farmland Trust;

Dr. R. Jim Hildreth, Elmhurst, IL; Ms. Dana Jackson, Land Stewardship Project; Dr. Dennis R. Keeney, Director, Leopold Center; Hon. Patrick J. Leahy, U.S. Senate; Dan Martin, Director, World Environment and Resources Program, MacArthur Foundation; Dr. Ned S. Raun, Stillwater, OK; Ronald L. Rosmann, farmer, Harlan, IA; R. Neil Sampson, Executive Vice President, American Forestry Association;

Edward Sills, Pleasant Grove Farms, Pleasant Grove, CA; Dr. David G. Topel, Dean, College of Agriculture and Director of Experiment Station, Iowa State University; and Dr. Stephen Viederman, President, Jessie Smith Noyes Foundation.

Advances in the production of cool season food legumes

F.J. Muehlbauer

Abstract. *Disease resistance, increased crop residues and altered plant and canopy design are the primary strategies being used to solve the major problems of cool season food legumes that are an integral component of cropping systems in the rainfed areas of the U.S. Pacific Northwest. Dry pea, seed pea and lentil predominate among these legumes, but there is increasing interest in chickpea. Several diseases are major hazards to production, including root rots, wilts, powdery mildew, Ascochyta blight, and viruses. Pea and lentil cultivars resistant to root rots, wilts, and powdery mildew are being developed and released. Progress is being made on resistance to viruses transmitted by aphids, including pea enation mosaic and bean leaf roll. Development of resistant cultivars has been the principal control strategy for several diseases: Ascochyta blight of chickpea and lentil; root rots and wilts of pea, lentil, and chickpea; powdery mildew of pea; and viruses of pea and lentil. Chickpea cultivars resistant to Ascochyta blight were recently made available to producers. Another problem is that crop residues are insufficient to control erosion. Research is underway on genetically increasing biomass and residue production in lentil and dry pea and on producing more lignified stems and other plant parts that are more resistant to breakdown during harvesting and subsequent tillage. Increased biomass also might increase grain yields and reduce harvesting losses. The semi-leafless and woody stem traits in pea, the bushy plant types of lentil and chickpea, and diverse pod traits in all the legumes have shown promise for increased yield potential, ease of harvest, and reduced shattering losses.*

Key words: Pacific Northwest, crop residues, canopy design, disease resistance, fungal diseases, viruses, pea, chickpea, lentil, aphids

Introduction

Grain legumes are produced on about 175,000 ha of the U.S. Pacific Northwest (PNW). These crops, including pea (*Pisum sativum* L.), lentil (*Lens culinaris* Medik.), and chickpea (*Cicer arietinum* L.), are important components of the region's cereal-based cropping systems. Grain legumes provide valuable alternative break crops for controlling some cereal diseases and grassy weeds that often are difficult to control within cereals. They also improve the nitrogen status of the soil through symbiosis with nitrogen-fixing *Rhizobium* bacteria.

Pea has been important in the region since the 1920s, whereas lentil was first grown commercially in 1937 (Youngman, 1968) and chickpea in 1981 (Kaiser et al., 1994). Pea occupies approximately 110,000 ha, followed by lentil with 60,000 ha and chickpea with about 5,000 ha (Suppliers Directory, 1994). From 1984 to 1993, total production averaged 150,000 tons of pea, 65,000 tons of lentil and 2,500 tons of chickpea (Fig. 1). About 80% of the total is exported.

The major production problems with these crops are diseases, which reduce yields, crop quality, and crop residues. Crop residues are becoming increasingly important in controlling soil erosion in the overwintering crops that follow grain legumes. This paper reviews advances in the control of diseases through breeding and discusses ways to improve biomass and residue production for more sustainable crop production.

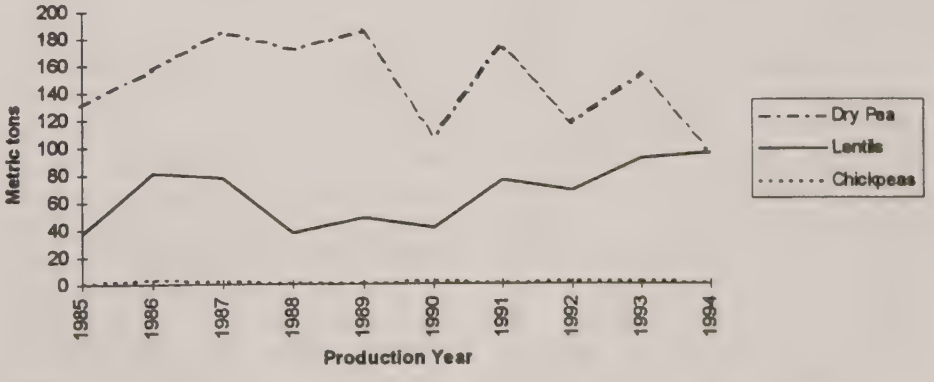

Figure 1. Production of cool season food legumes in the Palouse Region, 1985–1994.

Advances in Disease Control Through Breeding

Genetic resistance, the most economical and practical method of disease control, reduces or eliminates the use of costly pesticides. Plant resistance has been highly successful for controlling Fusarium wilt in lentil and pea and for controlling some foliar diseases of pea. It also holds promise for the long-term control of viruses in lentil and pea. Screening of germplasm collections and related wild species has uncovered sources of resistance that will be valuable for the continued improvement of cultivars. The following are diseases where substantial advances have been made through breeding.

Root rot, caused by *Fusarium solani* f. sp. *pisi* or *Pythium ultimum*, and often by both simultaneously, is the most widespread disease of pea in the world. It reduces yields by

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10% to 50% (van Emden et al., 1988; Kraft et al., 1994). The fungus usually invades the pea plant through the cotyledonary attachment areas or through the roots. Infected plants are stunted with yellow and necrotic lower foliage and usually die prematurely. The fungus also can attack lentil and chickpea, causing similar losses. Resistance to pea root rot appears to be inherited quantitatively, and some progress has been made in developing tolerant dry pea cultivars (Table 1). Efforts are continuing toward solving the root rot problem through breeding, and several germplasm lines have been released that have improved resistance or tolerance (Muehlbauer, 1992). That tolerance needs to be incorporated into acceptable cultivars.

Common root rot, caused by *Aphanomyces euteiches*, often is devastating (Kraft et al., 1994). In a recent survey, it was widespread in higher rainfall areas of eastern Washington and northern Idaho (Kraft et al., 1990). No germplasm lines have been found that have good resistance to the disease, but there are levels of tolerance that may be useful in reducing its severity (Muehlbauer, 1992; Kraft et al., 1994). It also affects lentil, but chickpea seems to have some resistance. In some higher rainfall areas of Idaho, "desi" chickpeas, small-seeded and variously pigmented types, have replaced dry pea in the rotation, primarily because of their resistance to aphanomyces root rot.

Cultural practices are considered essential for controlling common root rot. These practices include the crop rotations, careful tillage to avoid compaction, and tolerant cultivars. The most important control factor may be a long-term crop rotation in which pea is planted no more than once every five growing seasons.

Wilt, caused by *Fusarium oxysporum* f. sp. *pisi* race 1, can be a devastating disease of pea, but it is largely controlled by using resistant cultivars (Ali et al., 1994; Kraft et al., 1994). The fungus is soilborne and is known to have persisted in the soil for over 30 years while resistant cultivars were grown (Kraft et al., 1974). The inadvertent use of a susceptible cultivar in rotation for about 10 years was sufficient for the fungus to increase and cause disease. Crop rotations are ineffective in the control of Fusarium wilt; however, long term rotations should prevent the buildup of the pathogen and the development of new races.

Resistance to Fusarium wilt has been known for nearly 60 years and has been employed by breeders in developing improved cultivars. Economically important races of the pathogen include races 1, 2, 5 and 6; resistance to each has been identified through systematic screening of germplasm and later been shown to be conferred by a single dominant gene (Kraft et al., 1994). The identification of resistant selections is usually accomplished using "wilt sick" plots; however, pure culture tests in controlled environments also have proven successful. The pathogen has not developed new races in response to resistant cultivars, and breeders appear to have durable resistance available.

Fusarium wilt of chickpea caused by *Fusarium oxysporum* f. sp. *ciceris* causes a vascular wilt of chickpea in many areas of India, Pakistan, North and West Africa, Spain, Mexico and the U.S., although the disease has not been found in the PNW. Two recessive genes appear to be involved in the resistance (Smithson et al., 1983; Upadhaya et al., 1983a,b). Wilt resistance is easily incorporated into improved cultivars.

Powdery mildew of peas, caused by *Erysiphe polygoni* DC, spreads rapidly in seasons with warm days and cool nights. The disease reduces yields and seed quality. Resistance is controlled by a single recessive gene, and cultivars with good resistance are being developed and released.

Viruses, such as pea enation mosaic virus (PEMV) and bean leaf roll virus (BLRV), cause serious damage to pea and lentil, reducing yields and seed quality (Muehlbauer, 1992). These viruses also attack currently grown chickpea cultivars. Resistance is controlled by a single dominant gene in pea and by a single recessive gene in lentil. Resistant cultivars are considered important to sustained pea and lentil production in the PNW to maintain yields and enable the crop to produce sufficient residues.

Pea seedborne mosaic virus is a potentially serious pathogen of pea and lentil because it is seedborne and transmitted by aphids. The disease can cause severe stunting

Table 1. Progress in development of cool season food legume germplasm and cultivars with resistance or tolerance to important diseases.

Disease	Resistant/ Tolerant Germplasm Identified	Resistant/ Tolerant Cultivars or Germplasm Released	Reference
Pea			
Root rot	Y	Y	Muehlbauer, 1992
Common root rot	Y	Y	Muehlbauer, 1992
Wilt	Y	Y	Muehlbauer, 1992
Powdery mildew	Y	Y	Muehlbauer, 1992
Pea seedborne mosaic virus	Y	Y	Muehlbauer, 1992
Pea enation mosaic virus	Y	N	Muehlbauer, 1992
Bean leaf roll virus	Y	N	Muehlbauer, 1992
Sclerotinia white mold	N	N	Muehlbauer, 1992
Mycosphaerella blight	Y	N	Kraft (personal comm., 1995)
Ascochyta blight	Y	N	Kraft (personal comm., 1995)
Lentil			
Pea enation mosaic virus	Y	N	Muehlbauer, 1992
Bean leaf roll virus	Y	N	Muehlbauer, 1992
Pea seedborne mosaic	Y	N	Muehlbauer, 1992
Ascochyta blight	Y	N	Muehlbauer (unpub.)
Chickpea			
Ascochyta blight	Y	Y	Muehlbauer (unpub.)
Bean leaf roll virus	Y	N	Kaiser (personal comm., 1995)

and malformation of the plants, seed abortion, and a reduction in seed quality, depending on the plant's age at infection. Pea cultivars have been developed that carry the single recessive gene that confers resistance, and eight resistant pea germplasm lines also have been released (Muehlbauer, 1983). Screening of the USDA collection of lentil germplasm identified lines resistant to the virus (Muehlbauer, 1977). The resistance was shown to be conferred by a single recessive gene, which is currently being incorporated into improved cultivars. Resistant cultivars of both pea and lentil are needed to prevent yield and quality losses and to prevent cross contamination of these crops with the virus.

Ascochyta blight, caused by *Ascochyta rabiei*, is the major disease of chickpea in the PNW and has been the major deterrent to expanded production beyond the level shown in Fig. 1. The disease first appeared in 1983, soon after the crop was introduced to the region, and quickly developed into an epidemic (Kaiser et al., 1994). It has devastated crops in the Mediterranean region, Pakistan, India, western Asia and the U.S. (Porta-Puglia et al., 1994). Fungicidal control is very expensive and requires repeated applications. Plant resistance has been identified and was incorporated into three improved cultivars, 'Sanford', 'Dwelley', and 'Myles', which are now in production in the PNW. The new cultivars are expected to allow chickpea production to expand significantly with greatly reduced risk of Ascochyta blight.

The threat from Ascochyta blight remains because of possible genetic recombination of the fungus through the sexual stage. Such recombination may lead to more virulent pathotypes capable of causing disease in the recently released resistant cultivars, and therefore require additional breeding efforts.

Ascochyta blight of lentil, caused by *Ascochyta fabae* f. sp. *lentis*, is an important disease in western Canada, Turkey and parts of the Middle East. In Canada, the disease is especially prevalent when frequent rains occur between flowering and harvest. In such cases, the seeds can be so severely infected that they are not marketable. Chemicals for controlling the fungus are expensive and ineffective. Resistance to the disease has been identified in the cultivar 'Laird' (Slinkard, 1978), which is being used as a parent in the development of resistant cultivars. Resistance appears to be controlled by at most a few genes (Sark, 1994; Tay, 1989).

Advances in Plant Design

Cool season food legumes are vital components of farming systems of the PNW because their phenology is closely adapted to the climate. There is a narrow but adequate period for crop development, and the usually dry, favorable harvesting conditions ensure good quality crops. Food legumes usually are planted early in the spring, and flower soon after the onset of frost-free days. This usually insures that the flowers will not be damaged and will proceed with normal seed set. The crops mature before or at the same time as the onset of terminal drought. These crops make maximum use of the available water to achieve high yields. Summerfield et al. (1994) developed a model that accurately predicts phenological development from a small amount of data and is very useful for selecting germplasm adapted to specific environments.

The Natural Resource Conservation Service of the U.S. Dept. of Agriculture has established a residue level of at least 490 kg/ha as necessary to protect the soil from the erosive effects of rainfall and runoff after spring-seeded crops. However, food legumes generally do not protect the soil adequately. The reason is difficult to understand in view of estimated harvest index (H.I.) values. With H.I. conservatively estimated at .35 for lentils and .42 for peas (unpublished data), a 1.2 t/ha lentil crop would produce about 2.2 t/ha of residues, and a dry pea crop of 2.0 t/ha would produce about 2.8 t/ha of residues. Both amounts should be adequate; however, harvesting and tillage seem to reduce these amounts below adequate levels. Apparently, during harvest much of the residue produced by these crops is fragmented into small particles that are quickly decomposed or blown away. Tillage and planting of winter wheat further reduce surface residues. Research is ongoing to identify germplasm that will produce more biomass while not significantly reducing harvest index, so that harvestable yields may also be improved. Achieving this objective will provide legume cultivars for the cropping system that will produce increased residues, maintain or increase yields, and control soil erosion better.

Increased lignification of legume stems and pods would make the residues more resistant to mechanical and microbial breakdown. This would enable farmers to keep grain legumes in their rotations while complying with regulations regarding surface residues. The use of grain legumes that produce more residues or residues that break down more slowly would be an economical means of improving erosion control in the region. Genes for increased lignification are available in the pea germplasm collection and have been hybridized with adapted cultivars to transfer them to standard cultivars (Muehlbauer, unpublished). For lentil, the available germplasm must be evaluated for accessions with genes for woody stems comparable to those available in pea. The stems of chickpea are highly lignified. Good progress has been made in the development of tall, nonlodging genotypes in lentil. For pea, the 'Afila' gene (the gene that converts leaflets to tendrils) and the resulting "semi-leafless" plant types tend to have an upright and dense canopy imparted by the additional tendrils that intertwine and provide additional support for the plant stand.

Better management and improved fertility practices also should increase the amounts of biomass and residue. Recent results show that water deficits interact with nutrient supplies to limit residue production on erodible sites. Deep placement of phosphorus fertilizer has increased small grain residues by 25 to 50% (William L. Pan and Robert I. Papendick, Soil Scientists, Washington State University and USDA-ARS, respectively, Pullman, Washington; personal communications, March 1994). A more favorable residue situation would use soil and water resources better, since soil moisture would be retained more readily where the soil surface is adequately covered.

Crop residues, especially from legumes, are important animal feeds in the Middle East. The Food Legume Program of the International Center for Agricultural Research in the Dry Areas (ICARDA), located in Aleppo, Syria, has identified legume germplasm that produces more biomass and crop residues (Table 2). It is interesting that the entries with the highest grain yield also had the highest biomass yield at all locations (ICARDA, 1993). The results were similar

Table 2. Biomass, grain yield and harvest indexes of lentil germplasm estimated in trials conducted at three Middle East locations and at Pullman, Washington (adapted from ICARDA, 1993, with Pullman data added).

Location	Entry with Highest Grain Yield	Check with Highest Grain Yield	Location Mean
Terbol, Lebanon			
Biomass Yield	7550	6531	6157
Grain Yield	2977	2607	2477
Harvest Index	.39	.40	
Tel Hadya, Syria			
Biomass Yield	4668	4512	4107
Grain Yield	2191	1764	1574
Harvest Index	.47	.39	
Breda, Syria			
Biomass Yield	5600	3846	3453
Grain Yield	1962	1296	1104
Harvest Index	.35	.34	
Pullman, Washington			
Biomass Yield	4984	4204	5867
Grain Yield	2243	1850	2112
Harvest Index	.45	.44	

at Pullman with entirely different entries. This is contrary to the commonly held view that increases in grain yield must come from a change in partitioning and not from an inherent increase in yield potential. These results hold promise for the simultaneous increases of grain and biomass yields.

Advances in Environmental Stress Tolerance

Extremes in temperature and drought are important abiotic constraints to food legume production throughout the world, including the PNW. Other important abiotic constraints include nutrient toxicity, nutrient deficiency, salinity, and soil-related factors such as compaction. The effects of each of these are sporadic, but they can be devastating in some areas.

Drought and temperature extremes that occur during the reproductive stages usually cause increased flower drop and poor pod and seed set. Avoidance of drought and heat stress is the primary reason for fall planting of chickpea in western Asia and North Africa. With fall planting, the crop develops during the cool and moister winter season. It benefits from winter precipitation and lower evaporative demand to increase water use efficiency, and thereby increases its yield nearly threefold (Singh, 1993). Unfortunately, those are the conditions that also favor the development of Ascochyta blight. Research at ICARDA to develop chickpea germplasm resistant to Ascochyta blight has had good success; however, new pathotypes apparently can cause disease in the most resistant germplasm.

Lentil often is produced in areas with as little as 350 mm of annual precipitation. Consequently, the crop often is forced to maturity by terminal drought. In many areas of the Middle East and North Africa, winter planting is very successful and the lentil crop can take advantage of the cool and moist winter season with low evaporative demand to use available water efficiently.

Winter-hardy lentils hold promise in certain areas where it would be preferable to plant the crop in the fall to avoid problems associated with spring planting and to take advantage of the low evaporative demand of the winter season to increase crop growth. In many areas of the Middle East, including Turkey, lentil is planted in the fall or early winter. However, those areas have mild winters, so the lentil germplasm need not be highly winter hardy. Winter lentils for the PNW would require greater hardiness. Germplasm from Turkey was sufficiently hardy to survive most winters at a site near Pullman, Washington and led to the release of WH-2040 (Wilson and Hudson, 1978) and the later release of three improved winter-hardy germplasms (Spaeth and Muehlbauer, 1991). The released germplasm appears to have the necessary winter-hardiness for the region; however, quality traits necessary for acceptance must be improved. These germplasm lines have been used in crossing and selection to develop lines with winter-hardiness and acceptable quality traits. Selections are currently being tested in the field, and winter-hardy types with good quality traits are expected to be available soon for release.

Winter-hardy lentils will need to be planted with reduced tillage, with the residues and stubble from the previous crop, probably wheat, kept on the surface to prevent erosion. Fall-planted lentils in the PNW would not produce sufficient ground cover in the fall to protect the soil from the erosive effects of fall and winter rainfall. Fall-planted lentils have the advantage that they develop early in spring and flower and set seed in an earlier, cooler, more favorable part of the season. The crop also would mature earlier in the season, an advantage for improved crop quality.

Adaptation to mechanical harvesting is a major goal of lentil breeding programs throughout the world. In dry areas, lentil is not tall enough to permit mechanical cutting and combining. Also, soils in those areas often are stony and uneven, making mechanical harvesting even more difficult. In the Palouse, the crop has the benefits of sufficient height and soils with few rocks and stones. Besides the goal of collecting the maximum fraction of the seeds, another essential goal of harvesting legumes in most regions of the world is to collect the maximum amount of crop residues for use as animal feed. In the Palouse, in contrast, the soil must be left covered with crop residues.

Good progress is being made in developing tall, nonlodging lentil genotypes that should be more adaptable to machine harvesting. However, several questions remain concerning taller, more upright lentils. Because the canopy of more upright types closes more slowly, there may be increased weed competition, greater loss of water from the soil surface, and a reduced ability to intercept solar radiation (Hawtin et al., 1988). With dry peas, cultivars are being developed with the 'Afila' gene, which converts the leaflets to additional tendrils. That

plant type is considerably more resistant to lodging and may escape some foliar diseases that attack fallen vines.

Non-shattering or reduced shattering cultivars would improve lentil yield even though yield potential would not change. Shattering in the form of pod drop or pod dehiscence (splitting open of the pod) reduces seed yields by an estimated 17% in the U.S. Of the two types of shattering, pod dropping accounts for about two-thirds of seed losses (Erskine, 1985). Germplasm collections contain many small-seeded accessions whose pods remain intact during threshing. This is considered a valuable trait for the development of pod indehiscent, large-seeded types. Pod indehiscence in dry peas can be brought about through parchmentless pod genes that reduce the lignification of the pods. That trait was incorporated into 'Umatilla' yellow dry pea (Muehlbauer, 1987) and is responsible for greatly reduced losses from seed shattering. Its disadvantage is that in some seasons it is difficult for the combine to remove the seeds from the pods without damaging them.

Prospects for Cool Season Food Legumes

Cool season food legumes have a definite place in dryland farming systems where moisture is adequate, because they improve the soil's nutrient status and are a suitable alternative to cereals for controlling diseases and weeds. Further enhancement of the germplasm of these crops will come in the area of disease resistance; it will enable them to be produced with little use of chemicals and with economically sustainable yields and quality. The new emphasis on developing high residue legumes seems feasible in view of the estimated harvest indexes. It therefore appears possible that biomass and residues from these crops can be increased without harming seed yields. Germplasm that has improved disease resistance and can produce more biomass will help solve the residue problem from food legumes in the dryland production regions of the PNW. These developments will make these crops more sustainable in the region and provide germplasm that is valuable in other regions. Such germplasm would be useful in the Middle East, where legumes that produce high amounts of biomass are being sought for sustainable agricultural systems in which the seeds are used for food and the residues for animal feed. Increased biomass would also allow better adaptation to mechanical harvesting and could increase grain yields.

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RESOURCES

"Seeds and Science: Henry A. Wallace on Agriculture and Human Progress," a videotape of the Inaugural Henry A. Wallace Annual Lecture delivered by Senator John C. Culver on March 14, 1996, is $10; a written copy of the speech is $5; both are available from the Wallace Institute, 9200 Edmonston Road, #117, Greenbelt, MD 20770; (301) 441-8777.

"1996 SARE Project Highlights" is available from Valerie Berton, SARE Communications Specialist, 0322 Symons Hall, Zip 5565, University of Maryland, College Park, MD 20742; (301) 405-5270.

USDA videotapes summarizing the key concepts of the 1996 Farm Bill are available at no charge from Dottie Click, USDA Office of Communications, (202) 720-4197.

ATTRA's Resource List for internships, apprenticeships, sustainable curricula, and working farms programs is now on the agAccess World Wide Web site at http://www.mother.com/agaccess

"Farmers Markets '96: The What's Hot/What's Not Guide for Growers and Managers" is $5 from New World Publishing, 3085 Sheridan St., Placerville, CA 95667; (916) 622-2248.

"Good Earth Guide to Organics in the Upper Mississippi Region" is $5; in Minnesota, contact Donna Meyer, (612) 345-4925; in Wisconsin, contact David Engel, (608) 734-3273 or Faye Jones, (715) 772-3153.

"1996 National Organic Directory" is $34.95 plus $6 shipping/handling (CA residents add $2.75 sales tax) from Community Alliance with Family Farmers, P.O. Box 464, Davis, CA 95617; 1-800-852-3832 or (916) 756-8518 ext. 17.

"We All Live Downstream," a 30-minute video about urban and rural runoff, is $30 from Publications Orders, Agricultural Communications, Oregon State University, A422 Administrative Service Building, Corvallis, OR 97331-2119; (503) 737-2513.

"1996 Center Progress Report" from the Leopold Center for Sustainable Agriculture, detailing 15 recent research and education projects, is free from the Center, 209 Curtiss Hall, Iowa State University, Ames, IA 50011; (515) 294-3711; e-mail leocenter@iastate.edu

"Vegetable Farmers and Their Weed Control Machines," a video, is $10/made out to UVM Extension, from the Center for Sustainable Agriculture, 590 Main St., Burlington, VT 05460.

"Pesticide Use in California: Strategies for Reducing Environmental Health Impacts," a report of the Environmental Health Policy Program, is available from California Policy Seminar, 2020 Milvia St., #412, Berkeley, CA 94704; (510) 642-5514.

"Guide to Great Forestry and Natural Resources Publications" (NRAES-91, $10) and **"Mid-Atlantic Orchard Monitoring Guide"** (NRAES-75, $75) are both available from Northeast Regional Agricultural Engineering Service, Cooperative Extension, 152 Riley-Robb Hall, Ithaca, N.Y. 14853; (607) 255-7654; e-mail nraes@cornell.edu

"World Resources 1996-97" is available on the World Wide Web at http://www.wri.org/wri/wr-96-97; to order print version, contact World Resources Institute, 1709 New York Ave., NW, Washington, D.C. 20006; (202) 638-6300; e-mail philip@wri.org

"The Sierra Club Green Guide" is available at bookstores or for $25 plus $3 postage/handling from Sierra Club Store Orders, 730 Polk St., San Francisco, CA 94109.

"Small and Farmed Wetlands: Oases for Wildlife" is available from National Audubon Society, 666 Pennsylvania Ave., SE, Washington, D.C. 20003; (202) 547-9009.

Structural Adjustment, the Environment, and Sustainable Development, a World Wildlife Fund book, is $25 plus $4.75 shipping (CA residents add 7.25% sales tax, Washington, D.C. residents add 5.75% sales tax) from Island Press, Box 7, Dept. 2AU, Covelo, CA 95428; 1-800-828-1302.

"Monitoring Sustainable Agriculture with Conventional Financial Data" is $7 (MN residents add 6.5% sales tax) from Land Stewardship Program, 2200 4th St., White Bear Lake, MN 55110; (612) 653-0618.

"A Guide Through America's Farm Past," the 1996 Farm Museum Directory, is $5.50 from Stemgas FMD, Box 328, Lancaster, PA 17608.

"An Agriculture That Makes Sense: Making Money on Hogs" is $4 from the Land Stewardship Project, 2200 4th St., White Bear Lake, MN 55110; (612) 653-0618.

"Sustainable Agriculture in Print: Current Periodicals," updated version, is available from Alternative Farming Systems Information Center, National Agricultural Library, 10301 Baltimore Blvd., Beltsville, MD 20705-2351; (301) 504-7338.

"Understanding the Organic Foods Production Act: A Guide to the Recommendations of the National Organic Standards Board" is available from the Organic Trade Association, P.O. Box 1078, Greenfield, MA 01302; (413) 774-7511.

"Agricultural Research and Development, Public and Private Investments Under Alternative Markets and Institutions" (AER-735) is $12 from the Economic Research Service-NASS, 341 Victory Drive, Herndon, VA 22070; 1-800-999-6779.

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Diversification for new management systems opportunities in the Pacific Northwest

L.F. Elliott and P. Chevalier

Abstract. *Sustainable rainfed cropping systems are needed in the Pacific Northwest of the United States to reduce or eliminate wind and water erosion, improve soil quality, and control weeds with reduced chemical inputs. A grass seed cropping system is excellent for improving soil quality and for controlling erosion, and can be grazed by sheep to produce meat and wool. Tillage and residue management methods that create a rough surface to reduce wind and water erosion and increase water infiltration include: use of a chisel to create large clods; leaving residue on the surface; and use of the Paratill to shatter the soil to increase water infiltration with little disturbance of the soil surface. Including a legume in the rotation may help to break disease cycles, add N and C to the soil, and improve soil biological properties. The use of surface residues and tillage to control erosion and increase water infiltration may demand new approaches to weed control. Rhizobacteria that attack the roots of weeds but not of wheat may reduce the need for chemical herbicides. Research being conducted on these techniques in the Pacific Northwest of the United States and in other countries should soon result in guidelines for sustainable agricultural systems for the dryland, rainfed areas of the world.*

Key words: no-till, legumes, annual cropping, soil quality, crop rotations, erosion control, weed control, rhizobacteria, grass seed, dryland agriculture

The need for improving soil quality, conserving resources, and producing a sufficient supply of high-quality foods has made the development of sustainable rainfed cropping systems an international priority. To achieve this will require exploration of several alternatives: cropping systems that include animals; crop rotations that reduce or eliminate wind and water erosion while improving soil quality; and weed management methods that reduce the need for chemical inputs. We discuss several cropping systems and techniques being examined in the Pacific Northwest (PNW) of the United States: integrated sheep and grass seed production systems; crop residue management for soil protection; annual cropping; modified wheat (*Triticum aestivum* L.)/fallow systems using legume cover crops for erosion protection and water conservation; and rhizobacteria for biological weed control.

Contribution of the Agricultural Research Service, U. S. Department of Agriculture and Washington State University, Pullman, WA 99164. Trade names are provided for the benefit of the reader and do not imply endorsement or preferential treatment by the authors or the U.S. Dept. of Agriculture.

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Cropping Systems That Include Animals

A grass seed cropping system is excellent for improving soil quality and for wind and water erosion control (Stewart et al., 1976). When grazed by sheep, meat and wool also are produced (Fig. 1). In the Willamette Valley of Oregon, the seed fields (mainly grass) are grazed by sheep and spring lambs from approximately September through February. The dates of grazing vary according to the productivity requirements for the grass species. Grazing intensity is adjusted by moving animals from field to field.

Herbicides are usually applied in October. Sheep are removed from the area before herbicide application and are reintroduced according to the herbicide label. Changes in pesticide application regulations may jeopardize these cropping systems unless alternative weed control practices are available. The lambs usually are slaughtered for meat in March, with the seed crop harvested in July.

Rainfall in the Willamette Valley is high, ranging from 914 to 1720 mm in the grass seed production areas where sheep are grazed. This system might be applicable to areas with much lower rainfall if appropriate grass species are available and if grazing intensity is significantly reduced compared with the Willamette Valley.

Residue Management in Wheat/Summer Fallow Cropping Systems

Summer fallow is practiced over large rainfed areas of the Pacific Northwest to conserve water for winter wheat production (Papendick and Miller, 1977). Precipitation in the summer fallow area is 200 to 410 mm, coming predominantly as rain in the fall and spring, and as snow in the winter. Although rainfall is low, water runoff causes severe soil erosion, especially when the soil is frozen. Severe wind erosion also occurs

Figure 1. Sheep grazing seed grass stand near Corvallis, Oregon.

because tillage during fallow disaggregates the soil into fine particles that are readily transported by wind or water. Also, tillage reduces the soil organic matter content, with a consequent increase in soil erodibility (Smith and Elliott, 1990). Water and soil losses must be reduced in these areas to increase crop production efficiency and to protect and enhance soil quality.

The importance of tillage and residue management for water conservation has been recognized for a long time (Ramig et al., 1983). For example, soil surface roughness, either random or oriented, detains water and therefore prevents runoff. Postharvest subsurface tillage shatters the soil surface and improves infiltration when soils are frozen, provided it extends below the frost depth and the cracks remain open. This practice also helps control weeds, thus reducing water loss from transpiration.

The Paratill was developed in England for alleviating compacted soil layers and improving drainage (Pidgeon, 1983). It has bent-leg chisels that pass through the soil about 35 cm deep. The soil is shattered but not inverted, with little surface disturbance. Although its primary purpose is to improve drainage and shatter compacted soil layers, the surface-connected macroporosity it creates may improve infiltration during runoff from frozen soil. Elliott et al. (1995) showed that paratillage increased overwinter water storage by 36 mm in a 350 mm rainfall zone compared with the untilled control.

Surface crop residues also can improve water storage. For example, in Washington, of the total rainfall received from October through March, water storage was 72% for standing stubble, 68% for flailed stubble, and 51% for burned or plowed plots (Ramig et al., 1983). In another study, fall chiseling, fall disking, and no-till planting stored 87, 60, and 50%, respectively, of the September to May precipitation during cold winters (Lindstrom et al., 1974). Standing stubble increases water storage by entrapping snow and reducing wind movement, which reduces evaporation. Surface residues suppress water loss during the first stage of evaporation immediately following precipitation (Ramig et al., 1983).

Proper residue management is particularly important for achieving high yields in wheat/fallow systems. Kabakci et al. (1993) compared how three residue management methods—removal after harvest at the beginning of the fallow period, removal after the first winter, and no removal—affected water storage during the fallow year and growth, water use, and yield of the following spring wheat crop. In the first year of their study residue levels were high (3 t/ha), and plants grew better where residues were not removed than when they were completely removed immediately after harvest. With early removal, the plants had fewer tillers and lower water content in the flag leaf at anthesis, and fewer seeds per head and a lower yield at harvest. No differences were found among treatments in the second year, when the initial residue level was low (0.7 t/ha). Thus, when residue levels are high, residue removal soon after harvest and before the fallow year can reduce the growth and yield of the crop planted after the fallow year.

Increased water storage is usually attributed to the physical effects of soil and residue management on soil structure (Griffith et al., 1982). However, biological factors also may have a major influence on infiltration (Williams, 1966; Reganold et al., 1987). In laboratory studies, if N was limiting during the initial decomposition of residues, significant quantities of polysaccharides were produced. When residues low in N were added to soil, aggregate stability increased. The more that N was limiting, the greater the stability of the amended soil (Elliott and Lynch, 1984). Leaving residues with low N on the soil surface would effectively remove the residues from the influence of indigenous soil N and thereby enhance soil aggregation and soil microbial activity. This might increase water infiltration, because the more stable aggregates prevent surface crusting and maintain soil structure for improved water movement. Doran (1987), summarizing results from several plots across the southern and southeastern United States, found that microbial biomass, soil water content, and soil organic matter were greater near the soil surface in no-till plots than in conventionally tilled plots. This shows there is a relationship among tillage, residue management, residue N content, and biological activity.

Annual Cropping

Annual cropping in the traditional summer fallow areas provides overwinter residue cover, which improves erosion control and possibly increases overwinter water storage. Tillage and residue management can be used to increase overwinter water storage and increase the potential for successful annual cropping. Elliott et al. (1995), during a three-year annual cropping study with spring barley (*Hordeum vulgare* L.) in an area with 350 mm of rainfall, showed that residues increased water storage an average of 63 mm. However, the increased water storage did not increase barley yield, which averaged 1942 kg/ha during the three-year study. Yield may not have responded because the plots were on the droughtiest

areas in the field. The results show that annual cropping is likely to be economically feasible in areas of the PNW with rainfall of at least 300 mm.

Including Legumes in the Cropping System

Several factors must be considered if legumes are to be successfully employed in the rotation, including: the type of tillage; the amount and timing of rainfall; need for and availability of supplemental water; whether spring or fall seeding options are available; temperature and length of the growing season; whether the legume is being used for green manure or as a cover, strip, forage, or seed crop; and economic constraints. The agroclimatic region and economic factors dictate the conservation tillage practices and the intended use of the legume and thus the choice of legume. The benefits derived from legumes in a conservation tillage system are too important to be ignored. Legumes add N to the soil, control diseases, improve soil structure, decrease compaction, increase organic matter quality, and benefit microbiological relations in the rhizosphere.

Legumes or other forage crops in the rotation effectively slow the decline of soil organic matter or increase its equilibrium level. Adding organic materials regularly to the soil also helps to maintain soil organic matter content; possible materials include barnyard manure, sewage sludge, or green manures such as rye (*Secale cereale* L.), oats (*Avena sativa* L.), sweet clover (*Melilotus officinalis* [L.] Lam), vetch (*Vicia sativa* L.), and alfalfa (*Medicago sativa* L.). This practice, combined with reduced tillage, will rapidly increase organic matter content and improve soil properties (Papendick and Elliott, 1984).

Doolette (1978) described an ideal cropping system including a legume for improving soil organic matter and structure in semiarid regions. In an experiment in Australia, wheat yields were greater with an intensively tilled bare fallow-wheat rotation than with annual cropping. However, the yield increase was only temporary and appeared to be due to increased moisture storage and increased mining of the soil N in the fallow-wheat rotation; also, soil fertility declined, soil structure deteriorated, and soil erosion increased. In addition, in the red brown earth, soil aggregates greater than 0.2 mm declined from 52 to 24% and water infiltration decreased from 200 mm to less than 20 mm in three hours. When the bare fallow system was replaced by reduced tillage with a legume in the rotation, soil N increased. Eventual increases in soil organic matter and soil aggregation would also be expected (Lal, 1976). Therefore, Doolette (1978) concluded that the best cropping system was reduced tillage with a legume in the rotation. In another Australian study, Loch and Coughlan (1984) found that retaining surface residues increased both the organic C content of the 0-10 cm soil layer after five years and the dispersion ratio and dry aggregate size in the 0-4 cm layer of the no-till treatments.

Bakhtri (1978) pointed out the benefits of medic (*Medicago* spp.) in a rotation. In Algeria and Tunisia, soil N increased by 20 to 60 kg/ha after one year of a clean medic pasture. He quoted Mouffak's work in Tunisia that showed the same wheat yields with fewer cultivations when medic was in the rotation (Table 1). He also pointed out that with medic the soil was easier to work and that the same yields might have been obtained with less N added. In climates where they can be used, a winter legume cover crop increases soil organic C and total N compared with fields without cover crops, and increases soil pH (Lewis and Hunter, 1940; Wilson et al., 1982). Soil organic matter and organic N increased in a no-till clover (*Trifolium* spp.)/sorghum (*Sorghum vulgare*) system using clover as the winter cover (Hargrove, 1982). In a six-year study, Buntley (1986) reported increased yields for both tilled and no-till corn (*Zea mays*) following a wheat-vetch cover crop compared with conventionally seeded corn. These results relate primarily to the southeastern United States.

Lal et al. (1980) addressed the rapid deterioration of soil physical properties in a tropical soil following deforestation. They found that rice (*Oryza sativa* L.) straw mulch rapidly increased total porosity and had positive effects on saturated hydraulic conductivity, field infiltration rate, relative proportions of macropores, and moisture retention at –0.1 and –0.3 bars. The mulch also reduced runoff. From previous studies we can assume that if legumes are used for the mulch, the positive effects will be greater (Gilmour et al., 1948).

Legumes in a rotation influence soil biological properties favorably. Bolton et al. (1985) studied the soil on an organic farm that had used leguminous crops since 1909, most recently a green manure of Austrian winter peas (*Pisum sativum arvense* [L.] Poir), which together with native soil fertility provided N for plant growth. They compared this soil with soil from an adjacent farm that had received regular applications of anhydrous ammonia, P, and S at recommended application rates for the past 35 years. Urease, phosphatase, and dehydrogenase activities were significantly higher on all three sampling dates in the soil that had not received fertilizer, and soil microbial biomass was significantly higher on two of three dates. Soil organic matter also was greater and erodibility was lower. The organic farm had 16 cm more topsoil than the conventional farm (Reganold et al., 1987). Both operators used intensive tillage. Research is needed to learn whether rotational practices will have similar soil quality and erosion control benefits under reduced tillage.

Table 1. Effect of *Medicago* on wheat yield, Tunisia, 1974 (Bakhtri, 1978).

			Wheat/Medic		Wheat/Fallow	
Region	Variety	N (lb/A)	No. of Cultivations	Wheat Yield (lb/A)	No. of Cultivations	Wheat Yield (lb/A)
Tunis	INRAT-69	59	3	1,249	4	1,071
Fahs	Mahmoudi	30	4	892	5	803
Fahs	Ariana-66	45	3	2,855	5	2,320
Gaafour	Fx Aurore	30	3	1,517	5	1,428
Gaafour	INRAT 69	30	2	1,874	4	1,874
El Aroussainia		32	4	178	5	1,963

Besides growing well under conservation tillage, a legume must be adapted to a particular agroclimatic region. Hoyt and Hargrove (1986), adapting the work of Heath et al. (1985), summarized the characteristics of legumes primarily as cover crops in the south and southeastern United States, including some soil and climatic considerations (Table 2). Their summary allows researchers to select legumes for conservation tillage trials in the region. There is an abundant older literature on winter legumes; however, today's cultivars and cultural practices are very different. Such summaries, expanded to include seed legumes, are needed for all climatic regions so that informed choices can be made anywhere in the world.

Elliott et al. (1987) showed how strongly a legume in the rotation affected yield of winter wheat in the 530-mm precipitation zone near Pullman, Washington. With tillage and 0 N, winter wheat yields were, respectively, 1935, 3710, and 3467 kg/ha in a spring wheat/winter wheat (SW/WW) rotation, a pea (*Pisum sativum* L.)/winter wheat/spring wheat (P/WW/SW) rotation, and an Austrian winter pea/winter wheat/spring wheat (AWP/WW/SW) rotation. Winter wheat yield was 2197 kg/ha in SW/WW with a full N application. With no-till seeding, winter wheat yields with 0 N were, respectively, 1666, 2870, and 3407 kg/ha in SW/WW, P/WW/SW, and AWP/WW/SW. Winter wheat yield was 1986 kg/ha with the full N application in no-till SW/WW. There was no benefit of N application to the rotations that included the legume. The legume benefit was obvious.

Elliott et al. (1987) also compared several options for tilling legumes before planting winter wheat. They had three objectives: to compare how moldboard plowing, shallow tillage, and chemically killing the legume affect winter wheat yield; to assess how residue from Austrian winter peas, red clover (*Trifolium pratense* L.), hairy vetch (*Vicia villosa* Roth), and spring peas affect winter wheat yields; and to determine the feasibility of overseeding a forage legume into a spring cereal as a way of establishing legumes. Austrian winter peas had the highest dry matter and aboveground N production. Austrian winter peas may have been higher in N than spring peas because of earlier establishment. The amount of N fixed, in descending order, was: Austrian winter peas, hairy vetch, spring peas, red clover. However, the highest winter wheat yield (over 5000 kg/ha) occurred at all N levels following clover residue that was either moldboard plowed or shallow tilled. Yield response to added N fertilizer was low. These results suggest that the rotational benefits were greater than the N benefits. However, we do not know why the rotational effect was so large.

Legumes in a rotation benefit tillage systems, especially when used as a green manure. They reduce the demand for N from external sources, have a large rotation effect, reduce many pest problems, and improve soil structure and soil organic matter. Many grasses or grass-legume mixtures in the rotation also will provide these benefits, except that grasses do not supply N.

Some legumes are better than others in rotations, for several reasons. Some produce more biomass and fix more N. The rotational effect may be more marked with some than with others, and the residues of some may create allelopathy problems. Some legumes may promote better microbial-rhizosphere relations than others. There are many questions

Table 2. Commonly planted legumes and their characteristics, south and southeast United States (Heath et al., 1985; Hoyt and Hargrove, 1986).

Common Name	Scientific Name	Characteristics
Arrowleaf clover	*Trifolium vesiculosum* Savi	Adapted to lower South; late maturity; good reseeding; good insect resistance; grows best on well-drained, nearly neutral soils
Ball clover	*T. nigrescens* Viv.	Adapted to lower South; reseeds well; matures later than crimson clover but earlier than arrowleaf clover
Berseem clover	*T. alexandrinum* L.	Generally not winter hardy but produces abundant fall and winter growth where it survives
Crimson clover	*T. incarnatum* L.	Adapted to all of South; moderately tolerant of soil acidity; does not grow on calcareous or poorly drained soils; produces abundant growth in fall and winter
Persian clover	*T. resupinatum* L.	Adapted to clayey, wet or poorly drained soils of the lower South
Red clover	*T. pratense* L.	Grown as an annual in winter wheat only in the lower South; best production on fertile, well-drained soils
Rose clover	*T. hirtum* All.	Adapted to lower South on well-drained soils; low fertility requirement
Subterranean clover	*T. subterraneum* L.	Excellent reseeding; moderately tolerant of soil acidity; adapted to most of the South
White clover	*T. repens* L.	Grown as a winter annual only in the lower South; adapted to well-drained, medium-textured, nearly neutral soils
Blue lupine	*Lupinus angustifolius* L.	Adapted to neutral or slightly acidic soils of Coastal Plain; not very cold-tolerant
White lupine	*L. albus* L.	Adapted to neutral, fertile soils, especially in the lower Mississippi Delta; more winter hardy than blue lupine
Bigflower vetch	*Vicia grandiflora* Scop.	Intermediate in cold tolerance between hairy vetch and common vetch; adapted to most of the South
Hairy vetch	*V. villosa* Roth	Most winter hardy of cultivated vetches; well adapted to all of the South
Field peas (winter)	*Pisum sativum arvense* (L.) Poir	Winter hardy; well adapted to most of the South
Rough peas	*Lathyrus hirsutus* L.	Adapted to heavy soils in the lower South; reseeds well

about the adaptability of some legumes to conservation tillage, and some legumes are more suited to the prevailing climatic conditions than others. Much research remains to be done in these areas.

Biological Control of Weeds

The surface residues and reduced tillage needed for erosion control, and the increased water infiltration associated with reduced tillage, may demand new approaches to weed control. Increased water infiltration can result in increased downward movement of pesticides, which usually is undesirable. Also, pesticide uses are being restricted, requiring alternatives.

Rhizobacteria have the potential to suppress plant growth. Kennedy et al. (1991) determined the deleterious effects of native pseudomonads on downy brome (*Bromus tectorum* L.), a troublesome weed in small grains. They isolated *Pseudomonas* spp. from winter wheat and downy brome roots and tested their potential for biological control by screening them in agar and soil to identify those that inhibit root growth of downy brome but not of winter wheat. Of more than 1,000 isolates tested, 81 inhibited growth of downy brome roots and not winter wheat roots in the agar seedling bioassay. Six isolates consistently inhibited downy brome growth and not winter wheat in pots in the growth chamber. In nursery field trials in which downy brome was planted in rows and adequately fertilized, some bacterial isolates reduced downy brome populations up to 30% and shoot dry weight up to 42%. Field studies were also conducted at three sites in eastern Washington in which bacteria that inhibit downy brome were applied to wheat fields infested with natural populations of downy brome. Of the three isolates studied in the field, two reduced plant populations and aboveground growth of downy brome up to 31 and 53% compared with uninoculated controls. At two of the three locations, winter wheat yields increased by 18 and 35% because downy brome was suppressed (Kennedy et al., 1991).

Summary

The development of sustainable cropping systems has become a high international priority. Integrating animal grazing with crop production is very attractive where rainfall and cultural practices allow it. Residue management is very important in summer fallow areas for erosion control, improved water infiltration, and maintaining soil quality and soil stability. Proper residue management is important for maintaining optimum crop yields. Annual cropping in low rainfall areas is important for reducing erosion and improving water use efficiency. Studies are needed for establishing limits on these practices. An important area receiving increased emphasis is inclusion of legumes in the crop rotation. Legumes have strong beneficial rotation effects, fix N for succeeding crops, and appear to improve soil quality. Development of new weed control approaches, particularly biocontrol, is likely to decrease energy inputs and allow expansion of combination cropping-animal grazing systems.

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Land Grant Colleges Must Respond to New Agenda, Says Academy Report

The Land Grant University System must respond to the "transformation" of U.S. agriculture and "the new national interest," according to a recent report on Land Grant Colleges by the Board on Agriculture of the National Research Council, part of the National Academy of Sciences. *Colleges of Agriculture at the Land Grant Universities: Public Service and Public Policy* addresses the "adaptation of the land grant colleges to the public's changing needs and priorities" and recommends "public policy and institutional change that could enhance the colleges' role in serving the national interest."

Since the colleges' early years, the report says, U.S. agriculture has "undergone a transformation" which includes increased productivity, more stable and abundant farm output, and less costly commodities for consumers.

"The U.S. public is also increasingly concerned by how these primary production and processing activities interact with natural resources and the environment, rural communities, consumer health, safety, and ethics," the report states. "The monetary value of environmental quality, the natural resource base, human health, and the quality of life are often difficult to measure but are clearly of value to society.

"Diet-related health; food safety; water and air quality; soil, water and energy conservation; wildlife habitat; open space and the nation's landscape; and a 'way of life' that is associated with the family farm and rural communities, are all concerns of taxpayers who finance food and agricultural research, education, and extension."

The report cites changes in the increasingly concentrated farm production sector, in which "a small portion of all farms produce a majority of the farm output entering major commercial channels. . . . Industrial agriculture, characterized by vertical ownership (that is, control by a single corporate entity) of farming, processing, and marketing activities, is becoming more important. It is a trend that is challenging the traditional role of the public land grant colleges in serving independent farmers and ranchers whose agricultural operations are too small to conduct their own research or their own market analysis."

There is also a growing acceptance nationwide, the report says, "of alternative farming production technologies; and there is a growing recognition of the need for education and research that expand and improve technological options for sustainable production systems—systems that enhance the compatibility of farm profitability, environmental quality, and human communities."

In making its recommendations, the report states that "the land grant system has served the nation well, but changes are needed that reflect modern realities, challenges and opportunities. In particular, the system must increase its relevance to contemporary food and agriculture system issues and concerns; reinvigorate its commitment to the linkages among teaching, research, and public service; organize its programs and projects more efficiently and more in keeping with the regional and multistate requirements of many modern food and agriculture system problems; and enhance its accountability to the public." Within those themes, the report makes 20 recommendations for teaching, research, and extension.

Copies of *Colleges of Agriculture at the Land Grant Universities* are $35 plus $4 shipping/handling from National Academy Press, 2101 Constitution Ave., NW, Lockbox #285, Washington, D.C. 20005; 1-800-624-6242. Orders can be placed through the Internet at http://www.nas.edu

Tillage, seeding and fertilizer application technologies

Dale E. Wilkins

Abstract. *Tillage, seeding and fertilizing implements for rainfed cereal production with a winter precipitation pattern have unique functional requirements. In designing and developing implements for these systems, soil and water conservation principles are critical and must be integrated into the total production system. Plant diseases, insects, weeds, environmental degradation, crop yield, crop quality and economics all may be influenced by tillage, seeding and fertilizing implements. Advances have been made in implements for improved residue management, stand establishment and crop fertilization that leave more crop residue on the surface for soil and water conservation. However, they alter the seed and root zones, often resulting in uncontrolled pests, reduced yields, or increased production costs. Research is needed to integrate production implements into ecosystem management through automatic control systems for improved tillage, seeding and fertilizing. These systems should include field history mapping, real-time soil sensors, and models to link data bases with equipment functions.*

Key words: conservation, planting, equipment, disease, erosion, crop residue

Introduction

The Pacific Northwest (PNW) dryland production region has a winter precipitation pattern much like that of the Middle East (Fig. 1). Annual precipitation ranges from 250 to 550 mm, with over 60% occurring in November through March. In this region, summers are hot and dry and winters are mild and wet. At Pendleton, Oregon, in the southeastern part of this region, mean monthly temperatures is 19, 23 and 22°C, respectively, for June, July and August (National Oceanic and Atmospheric Administration, 1991). Winter temperatures below –30°C occur at Pendleton but normal minimum daily temperatures are above –20°C. These extremely cold days usually occur when the ground has snow cover, so there is little injury to fall-planted cereals.

The land is mainly steep, rolling loessial hills. The soils are permeable, well-drained silt loams that vary in depth from less than 1 to over 30 m. Winter wheat (*Triticum aestivum* L.), the primary crop, is grown in rotation with spring barley (*Hordeum vulgare* L.), dry peas (*Pisum sativum* L.) or lentils (*Lens culinaris* Medik) in high rainfall areas. In low rainfall areas, winter wheat is grown in rotation with summer fallow. Soil erosion is a serious problem because of winter precipitation patterns, steep slopes and low infiltration rates. Erosion rates above 25 t ha^{-1} yr^{-1} are common for this area, but erosion varies with slope, precipitation and land management (Papendick et al., 1985a).

Research on tillage, seeding and fertilization technologies for the PNW dryland farming region have concentrated on finding economical methods of soil and water conservation (Miller and Oldenstadt, 1987). Crop residue on and near the soil surface conserves soil and water (Allmaras et al., 1979). Tillage and planting systems that maintain a minimum of 30% residue cover on the soil surface after planting or maintain a least 1120 kg/ha of flat, small grain residue equivalent on the surface during critical erosion periods are defined as conservation tillage systems (Amer. Soc. Agric. Engineers, 1989). However, adoption of tillage, seeding and fertilization methods that conserve soil and water has been slow in the PNW (Allmaras and Dowdy, 1985). Control of weeds, diseases and insects in conservation tillage systems has been a complex and difficult challenge, especially in monoculture cereal production. Research emphasis is shifting from soil and water conservation to broader ecosystem management. This includes Integrated Pest Management and site-specific farming to provide sustainable

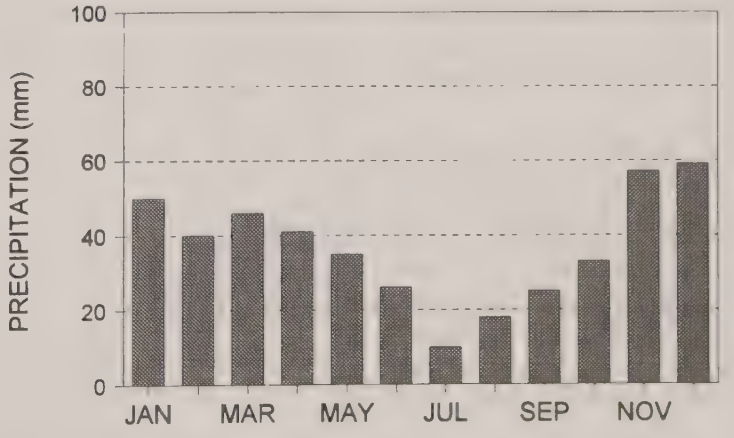

Figure 1. Mean monthly precipitation at Pendleton, Oregon.

Contribution of the U.S. Department of Agriculture, Agricultural Research Service. Trade names are provided for the benefit of the reader and do not imply endorsement or preferential treatment by the author or the U.S. Dept. of Agriculture.

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systems that improve air and water quality and conserve soil and water. The following sections describe developments and opportunities in tillage, seeding, and fertilization technologies for this region.

Tillage

The functions of tillage are to control weeds, diseases and insects, manage crop residues, create a seedbed, break or loosen hard soil layers, improve infiltration, and create a dry soil mulch for water conservation. Selecting and operating tillage tools to achieve the desired functions in the PNW requires compromises among the risks and benefits of these tillage functions. For instance, a tillage operation that buried most of the crop residue might benefit weed and disease control but could cause serious soil erosion.

The main objectives in managing crop residue with tillage for conservation of soil and water in the PNW are to maintain adequate crop residue on and near the soil surface for erosion control and to reduce evaporation by breaking capillary water conductivity. How much residue is retained on the surface depends on the initial amount of residue, its rate of decomposition, and the type tillage.

The initial amount of residue after harvest can be measured by hand collection or whole plant harvesting, or it can be estimated from grain yield. The last of these is common but inaccurate (McClellan et al., 1987; Wilkins et al., 1989). With this method, crop residue is estimated by multiplying grain yield by an assumed straw/grain ratio. The straw/grain ratio of winter wheat is often assumed to be 1.67, but it varies from 1 to more than 2. Whole plant harvesting and hand collection are tedious and time consuming, but must be used if accuracy is required.

Yields of cereal grain and straw are low in areas of low rainfall, and any tillage may reduce the surface residue below a level adequate for erosion control. Where annual precipitation exceeds 500 mm, wheat residue may exceed 10 Mg/ha. When the amount is this high, the residue is buried, chopped, cut, shredded or removed. Slot mulch tillage is an innovative approach that potentially can manage excess residue (Kenny, 1985; Saxton et al., 1981). The implement gathers the residue, makes a trench, and places the residue in the trench. The trench remains open to intercept runoff water.

Whatever method is used to manage residue, a uniform distribution at harvest is desirable. Modification of harvesting equipment can achieve this (Douglas et al., 1989). A new harvesting technology called "stripper harvesting" offers potential conservation benefits. It leaves cereal plant stems anchored to the soil and uniformly distributed. As with conventional harvesting, it is necessary to spread the chaff from cereals harvested this way (Fig. 2).

Crop residue is broken down or decomposed by biological processes. The decomposition rate is related to residue placement, nitrogen content and air temperature. Douglas and Rickman (1992) found a mathematical model that predicted decomposition of residues of wheat, barley, corn (*Zea mays* L.), and soybean (*Glycine max* [L.] Merr.). This model accurately predicted residue decomposition from Indiana to Oregon and Texas to Alaska.

For both primary and secondary tillage, the fraction of residue retained on the surface decreases as the amount of soil lifted above the residue increases (Koohestani and Gregory, 1985). Table 1 (Soil Conservation Service, 1988) shows surface residue retention factors for three primary tillage tools operated at 6.5 to 8 km/h in fields with 6700 kg/ha of grain straw. The size, shape, configuration, speed and depth of the tillage tool influence the amount of soil moved above the residue, and consequently residue retention.

Moldboard plowing buries more crop residue than either chisel plowing or disking (Table 1). Fig. 3 shows the distribution of coarse organic matter in the soil profile after moldboard plowing and chisel plowing of winter wheat stubble. Kraft et al. (1991) found that moldboard plowing buried crop residue in ribbons spaced according to the

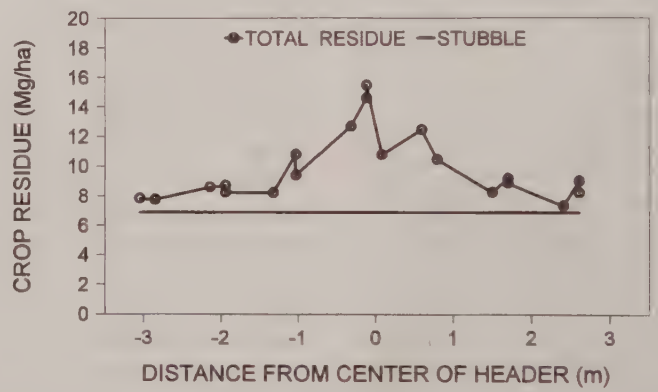

Figure 2. Residue distribution after stripper harvesting of winter wheat.

Table 1. Crop residue retention factors for three primary tillage implements operating a t 6.5 to 8 km/h in fields with straw exceeding 6500 kg/ha (Soil Conservation Service, 1988).

Primary Tillage	Tillage Depth (cm)	Retention Factor Surface Residue
Moldboard plow	15 to 20	0.30
Moldboard plow	20 to 25	0.15
Moldboard plow with trash rack	20 to 25	0.05
Tandem disc harrow	10 to 15	0.75
Tandem disc harrow	15 to 20	0.70
Chisel plow with straight points, 30 cm spacing	—	0.85
Chisel plow with straight points, 60 cm spacing	—	0.95
Chisel plow with twisted points, 30 cm spacing	—	0.55
Chisel plow with twisted points, 60 cm spacing	—	0.70

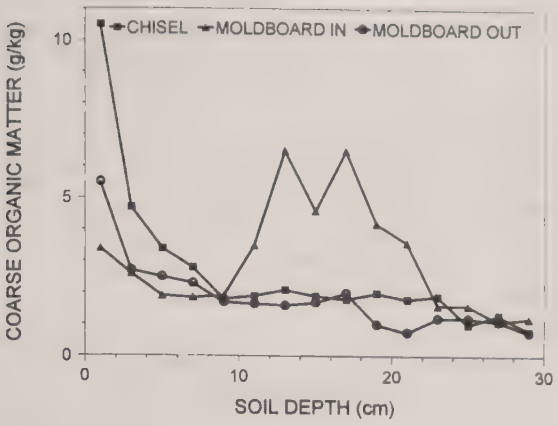

Figure 3. Effect of moldboard and chisel plowing on coarse organic matter distribution (adapted from Kraft et al., 1991). Curves labeled "moldboard in" and "moldboard out" represent samples taken in and out of the ribbons of buried residue.

width of the furrow slice. The curves labeled "in" and "out" in Fig. 3 represent samples taken in and out of the ribbons of buried residue. Even though chisel plowing buried residue, most of the residue remained in the top 10 cm, whereas moldboard plowing buried most of the residue below 10 cm.

Soil conditions also affect tillage tool performance. Shearing and cutting of residues are less effective under wet conditions (Choi and Erbach, 1986). Blades, knives and coulters do not cut tough wet residue, but instead push it into soft, wet soil. Dry soil and residue also alter tillage tool performance. Although residue cuts more easily when it is dry, tillage tools do not penetrate hard dry soils efficiently. Shallow tillage from lack of penetration leaves more residue on the surface than deep tillage because less soil is moved above the residue.

Almost 2 million ha in the PNW have deep soils (more than 1 m), cool growing seasons (less than 1000 growing degree days from January 1 through May 31), and from 250 to 350 mm annual precipitation (Douglas et al., 1992; Smiley, 1992). Approximately 90% is cultivated. The primary crop is winter wheat, which is rotated with summer fallow. Tillage is necessary to maintain sufficient soil water in the seed zone for fall emergence of wheat following summer fallow (Hammel et al., 1981; McClellan, 1987). Tillage with a sweep, disc harrow, chisel plow or moldboard plow, followed by two or three rod weedings during the summer, breaks the soil's capillary conductivity and maintains a dry soil mulch on the surface for reduced evaporation.

Tillage pans have developed at 20 to 40 cm in the PNW dryland farming region, especially in areas that are cool and moist with more than 1 m of soil (Wilkins and Kraft, 1988; Kraft et al., 1991). Deep tillage can alleviate this hard layer, but it reforms rapidly. In less than two years the compaction layer is almost as thick and hard as before deep tillage (Fig. 4). There is no evidence that yields are increased by breaking the hard pan unless more water is stored. Kenny (1985) showed that Paraplow™ tillage to 35 cm near Pullman, Washington increased water storage.

Seeding

Stand establishment in the PNW dryland farming region is critical, especially in the summer fallowed fields, because adequate water for wheat germination and emergence may lie deeper than 10 cm. Drills have been modified in many ways to enhance soil water in the seed zone (Erbach et al., 1983; Peterson et al., 1983; Wilkins et al., 1983; Papendick et al., 1985b; Hyde et al., 1987; Morrison et al., 1988; Tessier et al., 1991). Deep furrow or hoe drills are required to move dry surface soil away from the row so that seed can be placed in moist soil but not too deep (Wilkins et al., 1983; Tessier et al., 1991).

Peterson et al. (1983) developed a chisel planter to help manage crop residues at seeding. They coupled a double disc drill and chisel plow for direct seeding into untilled cereal or legume residues. This technique works well in the annual crop areas if the residue is not excessive. In low rainfall areas of the PNW, water in the seed zone may be insufficient for germination and emergence without tillage to break capillary conductivity. Therefore, chemical fallow is not practical in low rainfall areas (Hammel et al., 1981).

A cross-slot seeder developed in New Zealand and adapted for use in the PNW (Baker and Saxton, 1988) seeds directly into untilled residue. The cross-slot furrow opener consists of a single disc with L-shaped wings mounted on both sides of the disc. Seed or fertilizer is placed in the horizontal slots made by the L-shaped wings. The soil and residue are not strongly disturbed with this implement. It operates best in sod or cereal stubble because a firm seedbed is required for optimum performance. This drill is best suited for spring seeding in the PNW. Wilkins et al. (1992) established good stands of peas using this drill for direct seeding into wheat stubble.

Several no-till drills have been developed for direct seeding into legume or cereal residue (Hyde et al., 1987). These drills

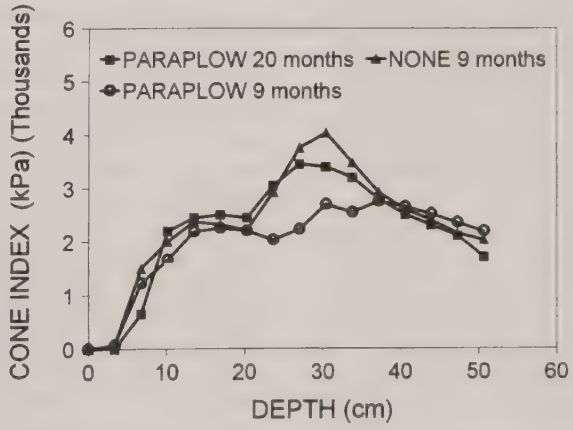

Figure 4. Effect of deep tillage and time on tillage pan in Pacific Northwest wheat-pea rotation (adapted from Kraft et al., 1991).

use double disc openers with residue management devices or tillage tools ahead of the openers. To obtain adequate soil penetration under adverse soil conditions, these drills must be massive to provide sufficient downward force to push the openers into the soil. If crop residue is not removed in front of double disc openers, residue will be "hairpinned" into the seed furrow. Residue in contact with seed is undesirable because it promotes drying and seedling disease injury (Cook and Haglund, 1991).

Bolton and Booster (1981) developed a strip-till seeder. This machine power tills strips 5 cm wide and 25 cm apart. Seed is placed in the tilled slot with double disc openers. Excess residue is not a problem for this drill, but its performance is impaired when soil water content approaches field capacity. This drill also works satisfactorily for seeding peas into wheat residue, especially when the soil is dry (Wilkins et al., 1992). Hoe-type drills can be used for direct seeding into cereal residue. Multiple ranks and wide spacing help accommodate high levels of residue, but more than 5 Mg/ha of wheat or barley residue may cause blockage. Smiley and Wilkins (1993) successfully used a deep furrow hoe-type drill with 41-cm row spacing to seed spring barley into barley stubble.

Fertilizer Application

Fertilizing cereal crops with conservation tillage requires special equipment and techniques to maintain crop residue on the soil surface and to insure proper nutrient placement. Several devices have been developed to place fertilizer near the seed at planting in conservation tillage systems (Hyde et al., 1987; Wilkins et al., 1987; Wilkins, 1988). These techniques have consistently shown an advantage for proper fertilizer placement in spring seeding, but fall cereal seeding has given mixed results. That is partially due to seedling injury from fertilizer toxicity in the fall.

The severity of fertilizer toxicity is related to several factors: source and application rate, soil water potential, and wheat variety all influence wheat germination and emergence significantly (Mahler, 1985; Mahler et al., 1989). Mahler (1985) conducted greenhouse studies by placing either ammonium nitrate or urea with winter wheat seed. Fig. 5 shows the relationships among N source, N rate and soil water at 5°C. Damage was more severe and emergence was further reduced as the temperature increased from 5 to 15°C. Injury increased as fertilizer concentration increased and soil water content decreased. Urea was more toxic than ammonium nitrate. These concepts apply to banding of fertilizer at seeding. High concentrations of toxic fertilizer placed close to seed in hot and dry soil will cause injury. The recommended minimum separation distance between seed and banded nitrogen fertilizer is 5 cm (Babowicz et al., 1983; Payton et al., 1985). Wilkins and Haasch (1990) found that the stand of winter wheat was reduced 10% with seed-fertilizer separation of 2.8 cm in a Walla Walla silt loam (coarse-silty, mixed, mesic Typic Haploxeroll) with marginal water for emergence (11.2%), a seed zone soil temperature of 28°C, and urea ammonium nitrate at 80 kg/ha banded below the seed in rows 41 cm apart.

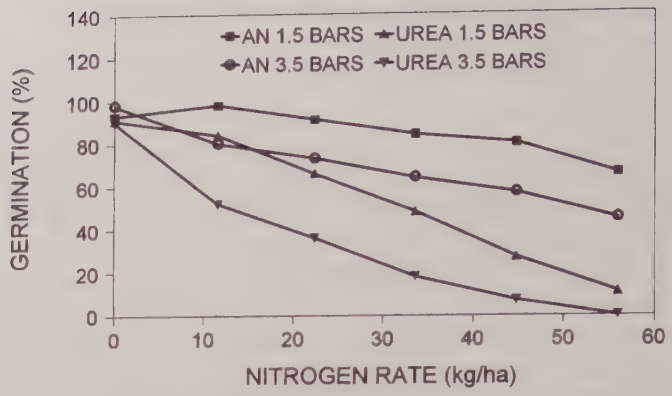

Figure 5. Effect of nitrogen source, nitrogen rate, and soil water tension on seedling emergence (adapted from Mahler, 1985). AN 1.5 Bars and AN 3.5 Bars represent ammonium nitrate placed with the seed into soil with 1.5 and 3.5 Bars soil water tension, respectively.

A new fertilizer application technology introduced by Baker et al. (1989) that has great potential in conservation tillage systems uses a spoke-wheel injection system that places fertilizer below the crop residue with minimum residue disturbance. This implement also can be used to inject fertilizer in fields that have established wheat plants. Womac and Tompkins (1990) adapted this technique for cotton production.

New fertilizer application technologies are emerging from research on site-specific farming in which different areas in a field are managed according to their specific fertilizer needs and yield potential. Peterson (1991) developed a system for variable fertilizer application rate using global positioning and computer-based field history maps.

Research Opportunities

A major effort was made in the last quarter century to develop dryland conservation farming systems for the PNW. Unique and innovative equipment and systems for erosion control resulted. This knowledge and equipment now must be integrated into sustainable, economical, high quality production systems that do not degrade the environment. This will require a broad-based multidisciplinary research program. The most fruitful areas for advancement in tillage, seeding and fertilizer application will be automation and control, such as site-specific farming. Application of technology for high speed information processing, satellite communication, and sensors will provide unlimited possibilities for equipment control. The following are four specific areas of research that would aid the PNW dryland production region in making the transition from conservation to ecosystem management:

1. Determine mathematical relationships among weather, crop residue, tillage, pests, soil environment and crop production.
2. Develop crop emergence models, especially for alternative crops such as canola (*Brassica napus*) grown in rotation with cereals.
3. Develop sensors to monitor tillage-zone water, soil nutrient status and crop residue while traveling at 5 to 10 km/h.
4. Develop automatically controlled tilling, seeding and fertilizing implements,

including: control of tillage tools to leave a desired amount of crop residue on the surface based on erosion potential; control of seeders to place seed at a desired depth and soil water content; placement of fertilizer at an optimum rate and location based on production potential and residual nutrients.

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"Overzealous" Pesticide Use Threatens Pollinators, Says Time Magazine

Pollinators such as honeybees, butterflies, and other bees are "in trouble, threatened by encroachment on open spaces, the felling and fragmentation of forests, industrial pollution and overzealous pesticide use," according to an article in Time (July 15, 1996). In parts of the Southwest, the article says, "excessive pesticide spraying of Mexican cotton fields just across the border has reduced populations of two moth species that pollinate certain cactus; as a result, the cactus flowers have withered and dropped."

Another example cited is the tallgrass prairie, an area which has shrunk from 5 million acres to only 200 acres. Butterflies are the main pollinators of the grasses and flowers in tallgrass prairie, but the variety of vegetation is decreasing as the butterflies are forced to forage for nectar in smaller prairie fragments. Because native insects are effective pollinators for crops such as blueberries and cranberries, farmers and entomologists are "actively encouraging native species....The rising star of the native pollinators is the blue orchard bee, a handsome metallic-blue creature that can pollinate an apple orchard with an efficiency that would shame even the hard-working honeybee."

BGH Sales "Go Sour," Says Wall Street Journal

Two years after its controversial introduction, bovine growth hormone (BGH), or bovine somatotropin (BST), "has yet to firmly establish its place in America's barns," according to *The Wall Street Journal* (August 16, 1996). A USDA survey shows that only 10% of the nation's 9.4 million dairy cows in early 1996 were receiving BST, "considerably fewer than the number thought to be using BST in early 1995."

Though "the product sparked loud consumer complaints over possible health hazards," the article says, "economics and bad timing — not consumer opposition — have been the main factors limiting the product's appeal." Use of BGH added to farmers' high feed costs and interfered with their traditional breeding routines, according to the newspaper. The cost of feeding livestock increased this summer as corn supplies fell to their lowest levels in nearly 50 years, the article said.

Exposure to Pesticides Reduces Immune System, Says WRI Report

Exposure to many pesticides "produces significant changes in immune system structure and function," according to a recent research report by the World Resources Institute. "There are substantial grounds for concern about the public health risks from pesticide-induced suppression of the immune system, especially in less developed countries and countries in transition," the report says. "There is evidence that these [immune system] changes can be accompanied by increased risks of infectious diseases and cancers associated with immuno-suppression, even in otherwise healthy populations."

As agricultural production intensifies in these countries, the amount of pesticides will increase, including "chemicals with known acute and chronic toxicity." The report recommends that "research and extension in integrated pest management programs should be significantly expanded . . . ."

Pesticides and the Immune System: The Public Health Risks is $14.95 + $3.50 S&H from WRI Publications, P.O. Box 4852, Hampden Station, Baltimore, MD 21211; 1-800-822-0504 or (410) 516-6963.

Crop traits for water stress tolerance

Edwin Donaldson

Abstract. *Cultivars vary considerably in how they respond to moisture stress throughout crop development. In areas of the Pacific Northwest with less than 250 mm of annual rainfall, winter wheat is under moisture stress most of the time from planting to harvest. Cultivars must be able to absorb moisture, germinate, and emerge under high temperature, poor seed zone moisture, and deep seed cover. Moisture stress slows emergence and seedling development and reduces most yield components, including number of tillers, seeds per spike, seeds per unit area, seed size, and seed weight per unit volume. Additionally, leaf senescence and maturity are early under moisture stress conditions. A cultivar cannot obtain its potential yield with less than adequate moisture; therefore, under moisture stress fewer tillers and seeds are produced. Which plant structures are reduced is determined by the growth stage of the plant during stress, while the extent of this reduction is determined by the severity of moisture stress and the genotype of the cultivar.*

Key words: wheat, moisture stress, cropping systems, emergence

Introduction

Crop traits that are advantageous for tolerance to water deficits vary greatly with the crop's environment. To describe desirable traits, we must specify the developmental stage of the crop when the water deficit occurs and the duration of the stress. Other stresses need to be understood, such as cold, heat, disease incidence and insect pressures. Certain traits may be advantageous in one environment and neutral or even harmful in another. If near-average production is essential every year, a different cultivar or even a different crop may be more desirable than one with a high yield in good years but a poor yield, or none at all, in unfavorable years. The possibility of replanting with the same crop or an alternative crop if the first crop fails must also be considered. For best moisture stress tolerance, growing alternative crops may be advantageous, such as barley (*Hordeum vulgare* L.) instead of wheat (*Triticum aestivum* L.) (Acevedo, 1987), or alfalfa (*Medicago sativa* L.) instead of other forage legumes (Peterson et al., 1992).

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This paper emphasizes traits advantageous to production in the Pacific Northwest (PNW) of the United States, particularly in areas with less than 250 mm annual precipitation. The PNW is dominated by winter wheat grown in rotation with summer fallow, with some production of spring wheat, spring barley, *Triticale*, and canola (*Brassica* spp.). Except for two weeks to a month in the spring, crops are under continuous moisture stress from planting to harvest. Historically, winter kill occurs about once in ten years, but it occurred in 1989 and in 1991. The 1991 winter kill was the worst on record. However, winter injury is quite frequent, as are late spring frosts. Diseases include the foliar diseases stripe rust (caused by *Puccinia striiformis*) and leaf rust (*P. recondita*), and the root and crown diseases bare patch (*Rhizoctonia* spp.), strawbreaker foot rot (*Pseudocercosporella herpotrichoides*), and dryland foot rot (*Fusarium culmorum*). Other pests include fall aphids, winter annual grasses, and broadleaf weeds. Other diseases and insects are less frequently of economic importance or are important in localized areas.

Cultural practices for winter wheat involve establishing an 8 to 16 cm dust mulch in the spring at the start of the summer fallow. This is usually accomplished with a primary tillage implement, such as a disc or cultivator, followed by a rod weeder. Summer fallow is maintained with the rod weeder, as necessary, for weed control. Under normal conditions, PNW soils have sufficient soil moisture (8-10%) immediately below the rod pan for wheat to germinate in the fall.

Cultivar Characteristics for Water Stress Tolerance

Germination and emergence

Stand establishment is the most consistent production problem in the low rainfall area of the PNW. A deep furrow drill is used to place seeds 3 to 5 cm into the moist soil below the dust mulch. Deep seeding often reduces emergence (Gan et al., 1992). Seed zone temperature ranges from 30°C or higher in late August to as low as 15°C around mid September. During that time seed zone moisture declines. Wheat emerges faster when seeded early because the soil is warmer and wetter. Other crops and some weeds respond similarly. In a model to predict emergence of the weed velvetleaf (*Abutilon theophrasti*), Forcella (1993) used moisture and temperature as the most important factors. Itabari et al. (1993) found that the emergence time for maize (*Zea mays* L.) increased by 2.8 degree days for each 1 cm increase in seeding depth and 3.2 degree days for each 1% decrease in soil moisture. A rain that prevents emergence because of crusting is more likely with later seeding because emergence is slower. The need to reseed because a surface crust prevents emergence is always a possibility. In general, better yields are obtained by early seeding the first time than by reseeding late, as may be necessary if the first seeding is delayed and fails to emerge. Seeding is usually completed before September 10.

Because of differences in seed size and hardness, cultivars of wheat (Lafond and

Baker, 1986), beans (*Phaseolus vulgaris*) (Hucl, 1993), and other legumes (Hadas, 1976) differ in speed of germination under stress. High temperature dormancy of freshly harvested seeds can restrict emergence of winter wheat, particularly under moisture limiting conditions (M.W. Simmons, Research Leader, USDA-ARS, Pullman, Washington, private communication, August 1995). Some cultivars have less dormancy than others.

In an experiment conducted for several years at the Dry Land Research Unit, Lind, Washington (unpublished), the highest yields were obtained when seeding was between September 10 and September 20. However, there was no statistical difference in grain yield among seeding dates in September. Reduced yields were obtained with seeding in late August or early October. This result was consistent for the five cultivars tested. However, some cultivars had a wider range of acceptable planting date than others. In the 1991-92 crop, seeding on September 20 was too late to obtain maximum yield. Seed zone moisture had decreased to where a good stand could not be obtained; where a stand was obtained, plant development was insufficient before winter because of moisture stress. In years favoring fall plant development, early seeding can create more fall growth than is desirable, extracting soil moisture in the fall that could be better used to increase grain yield in the spring (Winter and Musick, 1993).

For fall seeding in this area, cultivars must be able to germinate under low soil moisture and emerge rapidly through several centimeters of dry soil. Table 1 shows the results of a yield trial conducted in Horse Heaven Hills, Washington, where seeding was deep into marginal seed zone moisture. Coleoptile length is correlated with ability to emerge, particularly in semidwarf wheats such as 'Batum' and 'Andrews.' 'Buchanan' has the weakest straw. 'Weston' is the tallest. Tall plants with long coleoptiles and weak straw appear to emerge best. Semidwarfs with weak straw appear to emerge better than stiff-strawed semidwarfs. With adequate moisture, all winter wheat cultivars in advanced testing in Washington, Idaho, and Oregon will produce adequate stands when covered with 13 cm of soil, as they did in the Connell yield trial in 1992 (data not shown).

Table 1. Stand and grain yield at Horse Heaven, 1987, and growth chamber coleoptile length at 15°C.

Cultivar	Yield (kg/ha)	Stand (%)	Coleoptile Length at 15°C (mm)
Buchanan	2380	94	146
Blizzard	1840	78	117
Weston	1700	60	120
Hatton	1430	44	104
Batum	680	29	84
Andrews	820	23	107

Winter survival

Moisture stress is usually not considered a component of winter kill. However, winter kill in this area is usually associated with snow mold caused by *Typhula incarnata*, *Fusarium nivale*, or both, or with spring desiccation. Winters usually have several cycles of freezing and thawing, with plant growth resuming during the warm periods, as happened in 1979. Following winter injury, roots usually are not functional in the spring. The soil surface has been dried by wind and freezing. Plant crowns that have been weakened by winter conditions must reroot to initiate spring growth. In dry soil the crowns cannot reroot. Deep crowns may be beneficial for rerooting since the crown is more likely to be in contact with adequate soil moisture. In the two years where a single freezing event damaged the wheat, 1989 and 1991, a strong wind was accompanied by temperatures of –15°C to –20°C. In yield trials involving different rates and dates of seeding in 1989 and 1991, plants were more likely to survive where the seeding rate was high and the plants were large, possibly because the crown was protected from wind under these conditions. Plants protected from the wind by either crop or weed residue also survived. Also, plants in a wet, firm seed bed survived better (preirrigated vs. dryland planting). Cultivars with deep crowns again appeared to have some advantages. Some wheat cultivars establish crowns several centimeters below the soil surface when seeded deep. The crown is always established above the seed, however. 'Hatton' has a deep crown, while Buchanan has a shallow crown. Hatton is more winter hardy than Buchanan.

Early plant development

Moisture stress early in the plant's life delays development. When soil moisture is marginal, wheat seedlings can emerge from deep seeding and survive for at least four weeks with only two to four leaves above ground. However, crowns will not develop. Cultivars are needed that can extract moisture better. With adequate seed zone moisture, crowns will form in the dust mulch, but crown roots will not develop. Short crown roots developed in about ten days following a 20 mm rain at the Dry Land Research Unit in October 1993. The wheat had been planted about fifty days earlier. Similarly, NeSmith and Ritchie (1992) found delayed development in maize grown under moisture stress.

Cultivars differ in how they respond to row spacing and plant density. Plant density determines the number of individuals sharing limited resources; plant arrangement or row spacing controls the interception or retrieval of that resource (Wade et al., 1993). In the PNW, a higher seeding rate is needed for maximum yield when seeding is delayed, because the delay decreases plant development before winter. Spring seeding rates usually are higher and recommended row spacing narrower, partly because a deep furrow drill is not required for establishing a stand of spring crops. Producers in this area also use a higher seeding rate in the higher rainfall areas and under irrigation. Generalizations about how seeding rates must be adjusted for seeding date and row spacing cannot be extended to all locations and all crops (Silim et al., 1993). Cultivars also differ in their ability to germinate uniformly. Greater uniformity of seedling emergence could result in higher grain yields (Gan et al., 1992).

Rapid growth may be a disadvantage in winter wheat sown early where too much water can be extracted from the soil in the fall (Winter and Musik, 1993). However, early vigor and an accumulation of biomass before anthesis is usually an advantage in wheat (Turner and Nicolas, 1987), lentils (*Lens culinaris* Medik.) (Silim et al., 1993) and maize (Sinclair et al., 1990). Poorly adapted genotypes brought into this area produce less preanthesis biomass and mature earlier than adapted genotypes.

Roots

Roots from short season crops or crops whose seeding is delayed may not penetrate deeply enough into the soil to capture the available water (Winter and Musick, 1993). Root growth is greater in moist than in wet soil (Xu and Bland, 1993). When plants are stressed early and the stress is then removed, root growth recovers and continues later into the season (Meisner and Karnok, 1992). Roots of some cultivars penetrate compacted soil layers better than other cultivars (Kasperbauer and Busscher, 1991). Plants tend to root deeper in dry soil or when irrigated less frequently (Dwangan et al., 1992). Deep rooting ability is an advantage in many moisture deficient areas, but may also be a disadvantage (Ludlow and Muchow, 1990) or of no value where the rooting ability exceeds the wetting front. For water stress tolerance, plants need to extract as much moisture as possible from the soil. Early establishment of a deep and profuse root system is desirable both for extraction of soil water and competition with weeds. However, there probably is no advantage in having a rooting ability beyond the limitations of soil depth or wetting front. Rooting capabilities may be as specific for an area as other selection characteristics. The wheat cultivar 'Wanser' draws moisture from only about 1.4 m of soil while other cultivars draw moisture from much deeper (unpublished). Wanser has been competitive in the lower rainfall areas of Washington because its roots penetrate as deep as the wetting front in these areas.

Pests

Any pest that limits the amount of water available to the plant will increase moisture stress. Crop plants need to be competitive with troublesome weeds. Rapid early growth with quick ground cover is desirable. Good rooting cultivars that can extract soil moisture better than weeds have a competitive advantage. Resistance to prevalent sucking and chewing insects reduces the moisture required for high yield. Wheat cultivars susceptible to the toxin of the greenbug (*Schizaphis graminum*) may show a detrimental interaction when attacked by aphids while under moisture stress (Ryan et al., 1987). Asghar and Ingram (1993) simulated the chewing insect damage by mechanical defoliation of wheat after anthesis and found a loss in grain yield caused primarily by a reduction in kernel size, with results similar to post-anthesis chemical desiccation.

Diseases that restrict root growth, damage the crowns or restrict water movement can cause symptoms similar to drought stress (Talboys, 1968). Moisture stress appears to predispose plants to certain vascular diseases, such as dryland foot rot (caused by *Fusarium culmorum*) (R.J. Cook, Research Leader, USDA-ARS, Pullman, Washington, private communication, 1985).

We have tested the possibility of using a lack of disease symptoms to identify cultivars with drought resistance. Table 2 shows the potential loss of grain yield caused by dryland foot rot in 'Kharkof' winter wheat. One plot of the five replicates in a yield trial was severely infected (over 70% white heads). This procedure was tested by visually evaluating the response of four hard red winter wheats to dryland foot rot during two years (Table 3). These winter wheats are all adapted to the area. 'Lewjain', a soft white winter wheat with good tolerance to dryland foot rot was used as a check. Buchanan tends to overtiller and place itself under moisture stress. Hatton has the highest grain weight per unit volume, with Weston higher than Batum or Buchanan. Reaction to dryland foot rot gave only a rough estimate of tolerance to moisture stress. For moisture stress tolerance, as determined by grain yield and weight per unit volume when grown for several years under moisture stress, the order of the varieties is Hatton > Weston > Batum > Buchanan.

Osmotic adjustment

Osmotic adjustment varies with genotype (Morgan, 1977) and is positively related to grain yield (Morgan, 1983) when stress occurs either pre-anthesis (Ludlow et al., 1990a) or post-anthesis (Ludlow et al., 1990b). Osmotic adjustment has the advantage of being measurable in the greenhouse, where environmental variation can be controlled (Morgan et al., 1986). However, selection for high levels of osmotic adjustment may lower the tolerance to desiccation (Basnayake et al., 1993).

Table 2. Yield loss from dryland foot rot, *Fusarium culmorum*, for 'Kharkov' winter wheat at the Dry Land Research Unit, Lind, Washington, 1990.

	Yield (kg/ha)
Uninfected plots (4 reps)	1900
Infected plot	800
Yield loss (%)	57

Maturity and foliar characteristics

Many researchers agree that early maturity is associated with high grain yield under stress (Austin, 1987; Bidinger et al., 1987; Silim et al., 1993). However, in the PNW, the highest grain yields are usually obtained with later maturing cultivars, although these sometimes suffer from lower kernel weight due to moisture stress during grain fill. Under terminal moisture stress, early maturity to avoid the stress is advantageous. However, it is much less important where moisture is sufficient (irrigation) or where yields are limited by stresses occurring early in the development of the plant so that sufficient water is available to fill the kernels that do form. Early maturity limits the time for biomass production and grain fill. Better grain fill should be possible by selecting for

Table 3. Estimate of moisture stress resistance by reaction to dryland foot rot.

	Harrington 1988		Lind 1989	
Cultivar	White heads (%)	Yield (kg/ha)	Rating 0–5[1]	Yield (kg/ha)
Hatton	9	3000	1.7	3270
Weston	31	2650	1.5	3060
Batum	17	2930	4.7	2790
Buchanan	30	2590	4.5	3610
Lewjain	5	3330	0.5	2520

[1] Rating: 0 = no white heads; 5 = severe damage.

cultivars that are more efficient in transporting assimilates from leaves and stems into the grain (Turner and Nicolas, 1987; Kobata et al., 1992).

Many plant foliar characteristics prevent water loss during moisture stress, including small or narrow leaves; leaf rolling, folding and movement during stress; stomatal closure under stress; stomatal size and density; and cuticular resistance (waxy) (Austin, 1987; Ludlow and Muchow, 1990). Most moisture conserving foliar characteristics have the benefit of reducing moisture loss, but also reduce photosynthesis. Therefore, their value depends on the stage of crop development at the time of stress and the severity of the stress. Two wheat cultivars, Wanser and 'Moro', have been grown for thirty years in the driest wheat producing areas of Washington and differ morphologically. Wanser has narrow, upright leaves, shallow roots, and an awned, common head. Moro has large, drooping leaves, deep roots, and an awnless, club head. (A club head has much shorter rachis joints than a common head.) Early leaf senescence is usually a disadvantage even under stress (Acevedo, 1987), since leaves cannot produce assimilates after senescence. Under extreme terminal moisture stress, removing most of the leaves could be an advantage in cultivars that have assimilates to transport.

Moisture stress is particularly damaging during the reproductive stages of plant growth, causing sterility and deformed panicles in rice *(Oryza sativa* L.) (Takeoka et al., 1992). The extent of panicle injury varies among cultivars. Early kernel development in maize depends on a continuous supply of carbohydrates from concurrent photosynthesis (Schussler and Westgate, 1991). Moisture stress limits this supply, causing a lack of kernel development or less well developed kernels (NeSmith and Ritchie, 1992). Moisture stress may (Heatherly, 1993) or may not (Vieira et al., 1992) affect the germination and vigor of harvested seed.

Adequate fertilizer can reduce some adverse effects of moisture stress (Takeoka et al., 1992), increasing grain yield and water use efficiency in wheat, maize, and sorghum (*Sorghum vulgare*) (Onken et al., 1988). Maximum benefits from abundant fertilizer can be achieved only when responsive cultivars are used.

Techniques for Selecting Cultivars

Early vigor (Turner and Nicolas, 1987) and percentage ground cover (Silim et al., 1993) are associated with total biomass production and yield (Sinclair et al., 1990). Biomass production in cereal cultivars can be ranked using field spectroscopy at early growth stages (Smith et al., 1993), thereby eliminating much of the labor.

Haley et al. (1993) found that the rate of water loss from excised wheat leaves from plants grown under favorable moisture conditions was correlated with grain yield and weight per unit volume under moisture stress conditions. They concluded that selection for low rate of water loss in irrigated environments could benefit grain yield and weight per unit volume in dryland environments, despite observed genotype by environment interactions and the lack of any difference in rate of water loss in dryland environments.

Selection for lower transpiration rates from full canopy coverage improves water use efficiency. Hattendorf et al. (1990) identified an alfalfa cultivar with lower transpiration, indicating that selection for this characteristic might be possible in other crops.

In environments with terminal drought stress, a chemical desiccant to defoliate the plants after anthesis can be used to identify post-anthesis stress resistance. For this procedure to work, plants must have high carbohydrate reserves in the biomass combined with efficient translocation of assimilates to the grain (Hossain et al., 1990). Regan et al. (1993) found that for best results, selection should be confined to wetter sites or seasons.

Final testing must be carried out in the field in the environment where the cultivar will be grown. Field testing, unfortunately, is affected by many environmental variations within a year and among years. Small variations in the field that are undetectable to the eye and that seem small when tested (for example, seed zone moisture) can have significant effects on plant growth. Under poor seeding conditions, wheat will emerge and grow in a chaff row created by the harvest of the previous crop, although moisture between the chaff rows is insufficient for germination and growth. This problem was not observed with a 3.5-m harvester header, but was noticeable when a 5-m harvester header had been used to harvest the previous crop. Tractor tracks from the summer fallow tillage operations sometimes can be detected by reductions in final stand and early plant growth because of increased evaporation in the track. A crawler tractor, which creates less compaction than a wheel tractor, helps reduce the problem. In evaluating field performance, multiple locations, years, seeding dates, and replications are even more important in dry environments than in high moisture environments.

In the advanced lines shown in Table 4, yield selection was for competitive yields in low-yield locations and a favorable yield increase in high-yield locations. If the average across locations is the variable used for selection, the small differences in yield on poor locations can be lost by the larger yield differences in high-yield locations. This becomes equivalent to testing only in more favorable environments, which may not be reliable (van Oosterom et al., 1993). Grain yield was not the primary reason for selecting either WA007678 or WA007679. With additional data across years, regression analysis of yield vs. yield potential of the environments will aid in final evaluation.

Comparison of cultivars for grain yield and weight per unit volume among locations differing in stress is easily accomplished using line source irrigation. Mahalakshmi et al. (1990), using pearl millet (*Pennisetum glaucum* [L.] R. Br.), concluded that when genotype response to the stress gradient is linear, the difference in response between the high (irrigated) treatment and the low (unirrigated) treatment can be used for genotype evaluation with little loss of information.

In the lower rainfall areas of the PNW, moisture stress that limits grain yield often occurs before or during anthesis. As rainfall increases, terminal moisture stress is more likely. Thus, within the desired area of adaptation of cultivars, the yield-limiting moisture stress could be either pre- or post-anthesis. Desirable genotypes should have competitive yields under both kinds of stress and should maintain good seed weight per unit volume. In Table 5, the yield-limiting stress was pre-anthesis at Lind and terminal at Harrington. Weston and 'Hoff' showed small differences in yield between the sites because of the poor performance at Harrington. Weston and Andrews showed the least change in weight per unit volume. Evaluated within this data set, Andrews has the desirable attributes of good yield at the

Table 4. Yields (kg/ha) of commercially grown hard winter wheat cultivars and two advanced lines grown at four locations in eastern Washington varying in available moisture, 1993.

Cultivar	Horse Heaven	Finley	Waterville	Lind Preirr.	Average
Hatton	1946	2796	3061	4449	3063
Weston	2061	3054	3184	4122	3105
Blizzard	2095	2707	2850	3571	2806
Buchanan	1980	2714	3646	3939	3070
WA7678	1939	3503	4061	4136	3410
WA7679	1898	2925	3993	3551	3092

Table 5. Effect of time of maximum moisture stress on yield and weight per unit volume for hard red winter wheat grown on dryland at Lind and Harrington, Washington, 1990. Harrington shows terminal stress, low grain weight per unit volume. Stress at Lind was at an earlier plant growth stage, limiting yield but with sufficient moisture to fill the kernels.

	Yield (kg/ha)			Weight per unit volume (kg/hl)		
Cultivar	Lind	Harr.	Diff.	Lind	Harr.	Diff.
Hatton	2476	3531	1055	82.1	76.1	6.0
Weston	2469	3156	687	81.4	76.8	4.6
Andrews	2490	3939	1449	78.8	75.6	3.2
Hoff	2290	3197	898	81.4	75.0	6.4
Buchanan	2054	3293	1239	79.9	73.3	6.6
Batum	2354	3816	1462	78.7	72.0	6.7

low-production site, high yield at the higher-production site, and a small difference in weight per unit volume. Andrews is the earliest maturing cultivar in the set.

At Lind, spring wheat was seeded in adjacent areas on summer fallow ground and on ground that had spring wheat the previous year (Table 6). Unseasonably hot weather occurred between Julian days 130 and 140, placing the wheat under stress. The earlier heading (anthesis) cultivars had the highest weights per unit volume in the area cropped annually, but had poor grain yields under both summer fallow and annual cropping. An exception was 'Express', which yielded well under annual cropping and showed little difference in weight per unit volume between treatments. 'Wampum' showed favorable yields in both treatments, but had considerable difference in weight per unit volume. Selection for high yield under Washington conditions has resulted in later maturing genotypes that lose weight per unit volume under severe terminal moisture stress. Low weight per unit volume under stress conditions is a major constraint in developing higher yielding cultivars of both spring and winter wheat in Washington State.

Table 6. Effect of moisture stress on yield and weight per unit volume of spring wheat grown on summer fallow and with annual cropping, Lind, Washington, 1993.

		Yield (kg/ha)			Weight per unit volume (kg/hl)		
Cultivar	Head Date	Fallow	Annual	Diff.	Fallow	Annual	Diff.
Spillman	156	2660	1565	1095	78.7	68.9	9.8
Wampum	156	2619	1687	932	79.6	69.9	9.7
Express	154	2422	1633	789	79.9	75.3	4.5
Butte 86	152	2306	1286	1020	79.5	73.4	6.1
906R	150	2306	1429	877	79.5	76.2	3.2

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Diseases of wheat and barley in conservation cropping systems of the semiarid Pacific Northwest

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Abstract. *Diseases continue to be important constraints in wheat and barley conservation cropping systems in the semiarid Pacific Northwest. Several diseases are more damaging in high than low-residue seedbeds, and in crops planted during early autumn to reduce soil erosion during winter, especially unirrigated winter wheat in rotation with summer fallow in low rainfall zones (250-400 mm). Changes in cropping systems in the region have made disease management and maintenance of yield goals and farm profitability more challenging because disease management often is more complex and expensive with conservation tillage than inversion tillage. Practices being developed to meet this challenge are reviewed for diseases that are particularly troublesome in conservation farming systems of the Pacific Northwest.*

Key words: disease control, plant pathogenic fungi, viruses, nematodes

Small grain production systems in the semiarid (<500 mm precipitation; winter-dominant pattern) Pacific Northwest (PNW) were developed to produce maximum economic returns. Since yield has been the primary determinant of farm income, management practices evolved to produce high yields with low season-to-season risk. Consequently, some areas experienced severe soil erosion and the potential for contamination of ground water with nitrate. This led to widespread concern over the quality and sustainability of soil and water resources and to interest in farming systems that minimize or alleviate these concerns (Allmaras et al., 1985; Ramig and Ekin, 1987; Cook, 1992). Every component of crop management is being reassessed to determine how it affects other components. Studies of plant pathogens and disease control are important aspects of this cost/benefit assessment (Wiese et al., 1987; Cook, 1990, 1991a).

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Foliar diseases were the first to be studied intensively in the PNW, with rusts and smuts receiving particular attention. Some foliar diseases continue to cause routine economic loss, but most are not important because of integrated genetic, chemical, and cultural management practices. Root- and crown-infecting fungi now are the primary yield-limiting diseases of wheat and barley. Nearly every root disease, soilborne pathogen, or nematode problem known to affect wheat is economically important somewhere in the region (Cook, 1992). Each requires continuous oversight to protect the integrity of the wheat and barley industries. This is particularly challenging because combinations of climate and soils are highly variable (Douglas et al., 1990) and strongly influence the damage potential of each soilborne pathogen in the PNW. Interactions among pathogens, parasites, vectors, susceptible plants, and abiotic stresses in the air and soil are complex and difficult to define with precision.

Over thirty wheat and barley diseases are of specific concern in the PNW (Mathre, 1982; Wiese, 1987; Cook, 1990; Cook and Veseth, 1991; Line and Cu, 1992; Smiley et al., 1993a): barley scald; barley stripe; barley yellow dwarf; black chaff; Cephalosporium stripe; common bunt; common root rot; covered smut; cyst nematode; dwarf bunt; ergot; eyespot; flag smut; Fusarium crown and root rot; head scab; leaf rust; lesion nematode; loose smut; net blotch; physiologic leaf spot; pink snow mold; powdery mildew; Pythium root rot; Rhizoctonia root rot; root-knot nematode; Septoria leaf and glume blotches; sharp eyespot; speckled snow mold; spot blotch; stem rust; stripe rust; take-all; and wheat streak mosaic. Important management practices for selected diseases are summarized in this paper.

Fungal Diseases

Smut diseases

Smut diseases are caused by seed- and soilborne fungi. Smuts in the PNW include common bunt (caused by *Tilletia tritici*), dwarf bunt (*T. controversa*), flag smut (*Urocystis agropyri*) and loose smut (*Ustilago tritici* on wheat; *U. nuda* on barley) (Holton and Heald, 1941; Hoffman, 1982; Wiese, 1987). *Ustilago* species spread as internal parasites of seed; other smut fungi are external contaminants of seed or survive as teliospores in soil.

Common bunt, flag smut and loose smut pathogens infect seedlings before the coleoptile emerges from soil. The short interval between planting and seedling infection allows control of these diseases with fungicide seed treatment because infection occurs before the fungicide becomes ineffective due to hydrolysis and dilution. Resistant cultivars are available, but without

chemical control the pathogens are notorious for their ability to develop virulent new races that can infect newly released resistant cultivars. Control of these smut diseases was stabilized by combining resistant cultivars, fungicide seed treatments, and planting dates that are least favorable for infection. Typically, these diseases become highly damaging if growers plant a susceptible cultivar for several successive crops without applying a fungicide seed treatment.

Unfortunately, the effective and inexpensive control of smuts by fungicides caused plant breeders to focus on breeding objectives with more immediate economic benefits. Many cultivars released during the past decade are susceptible to all the smuts (Smiley and Patterson, 1995a). As a result, common bunt, flag smut and loose smut occur on a few plants in many crops, presumably in response to nonuniform application of the fungicide seed treatment. A constant vigil is required to ensure that new races or fungicide-resistant strains of the pathogens do not circumvent currently available genetic resistance and fungicides.

Dwarf bunt, known locally as TCK smut (for *Tilletia controversa* Kühn), reduces yields and is responsible for restricted export of PNW wheat to China (Purdy et al., 1963; Hoffman, 1982; Trione, 1982). Longer and more severe soil cooling is required for infection by *T. controversa* than by *T. tritici*. The dwarf bunt pathogen therefore infects autumn-sown wheat seedlings during winter. Resistant cultivars are available but are not extensively grown because their yield potential typically is lower than that of susceptible cultivars in years when dwarf bunt is not severe. The fungicide difenoconazole is highly effective for controlling dwarf bunt (Sitton et al., 1993; Keener et al., 1995) and was registered for commercial use during 1994. Previously registered fungicide seed treatments were not effective against dwarf bunt, presumably because of the long time between planting and infection.

Rust diseases

Rusts were among the first diseases recognized on wheat in the PNW. Stripe rust (caused by *Puccinia striiformis*), leaf rust (*P. recondita*) and stem rust (*P. graminis*) of wheat continue to cause losses. Stripe rust causes the greatest and most frequent damage in the region. Destructive epiphytotics of stripe rust are estimated to occur in three of four years. Stripe rust of barley also entered the region during 1995. Leaf rust is becoming increasingly important because of control of stripe rust, intensive wheat management, and increased use of irrigation. Stem rust becomes highly damaging at high elevations, where the crop matures during late summer, or at low elevations during cool, moist summers that delay maturation.

Breeding for resistance to all three rusts has been a principal objective of plant breeding programs for many decades (Schafer, 1987; Wiese, 1987; Roelfs et al., 1992; Chen and Line, 1993). Although significant progress has been made, the ever-evolving rust pathogens remain a challenge. A recent practice involves the use of multilines and cultivar mixtures to slow the rate of rust epiphytotics (Finckh and Mundt, 1992). Application of the fungicides triadimefon or propiconazole also inhibit epiphytotics (Conner and Kuzyk, 1988). Planting as late as practicable during autumn shortens plants' exposure to showers of rust spores and increases the time from the preceding harvest, thereby breaking the continuity of living susceptible plants, called the "green bridge." The need to predict and control rusts led to the development of MORECROP, an expert system that integrates climate and cropping system variables to suggest control options for the most important diseases of wheat in the PNW (Line and Cu, 1992).

Culm-infecting foot rot pathogens

Eyespot. Eyespot, caused by *Pseudocercosporella herpotrichoides* and known locally as Cercosporella foot rot or strawbreaker foot rot, is highly damaging to winter wheat but not spring wheat (Wiese, 1987). The pathogen survives in the residue of plants infected while alive. Spores are produced on such residues at the soil surface and are splashed by rain onto culms of seedlings. Mild winters and cool, wet springs favor eyespot development. Crop management strategies have a strong influence on disease incidence, with time of planting especially important. Seeding in late autumn reduces plant size during autumn and therefore reduces the plant surface exposed to infection. Early planting favors a dense crop canopy with high humidity and long wetting periods in the infection court at the base of the culm.

Eyespot is less damaging with minimum- or no-tillage than with moldboard plowing (Cook et al., 1978; Herrman and Wiese, 1985). However, it still may be damaging in high-residue systems, where seedlings develop more slowly and are smaller during winter. Rotation of winter wheat and fallow is particularly conducive to eyespot in low-residue seedbeds (Bruehl et al., 1968). Tillage or other mechanical soil disturbance in established crops during the spring may increase the severity of eyespot, but nitrogen application has little influence (Bruehl et al., 1968; Herrman and Wiese, 1985).

Wheat cultivars differ in their tolerance to infection (Murray and Bruehl, 1986; Allan and Roberts, 1991), and cultivars with acceptable resistance are now available. Fungicides that hydrolyze to carbendizem have been used to reduce disease severity and increase yield for more than a decade (Herrman and Wiese, 1985). However, strains of *P. herpotrichoides* emerged that have high tolerance to these fungicides, and benzimidazole fungicides are no longer effective in many fields (Murray et al., 1990).

Sharp eyespot. Sharp eyespot (caused by *Rhizoctonia cerealis*), another disease of small grains, is difficult to distinguish from eyespot. The severity and prevalence of sharp eyespot is currently being studied on eyespot-resistant cultivars. The importance of accurate diagnosis of sharp eyespot is shown by a finding in France where, as in the PNW, eyespot had been considered the dominant disease. When a fungicide was applied to control eyespot in France, the incidence of sharp eyespot increased markedly (Cavelier et al., 1985). This phenomenon could explain instances in which "eyespot" purportedly damaged eyespot-resistant cultivars in the PNW, or where properly applied fungicides failed to control "eyespot" in fields where fungicide resistance is not documented.

Root-infecting pathogens

Take-all. Take-all (caused by *Gaeumannomyces graminis* var. *tritici*) becomes acute in irrigated wheat and barley (Folwell et al., 1991), but is chronic in unirrigated fields, especially where small grains are planted annually. The pathogen survives in infested crop debris and colonizes the roots of young plants. Take-all has been studied extensively (Asher and Shipton, 1981; Kollmorgen,

1985). Sources of genetic resistance are unavailable and seed treatment with the fungicide triadimenol has been unreliable (Bockus, 1983; Bateman and Gutteridge, 1984; Garcia and Mathre, 1987).

Soil and crop management continue to be the primary way to reduce damage from take-all. Rotations involving nonhost crops such as annual legumes suppress take-all if grassy weeds are thoroughly controlled throughout the rotation. Deficiencies of phosphorus and possibly of other nutrients suppress root growth and predispose seedlings to infection. When fertilizer is banded below the seed at planting, plants growing in pathogen-infested soil yield more grain than with any other time or manner of fertilizer application. Practices favoring root absorption of ammonium ions over nitrate ions reduce damage from take-all in high rainfall sites and irrigated fields. Such practices include treating ammonium-supplying fertilizers with a nitrification inhibitor or a competitive inhibitor of nitrate absorption, such as a chloride salt (Smiley and Cook, 1973; Smiley, 1978; Christensen and Brett, 1985). Keeping the soil moderately acidic (pH 5.0 to 5.5) reduces take-all without significantly reducing nutrient availability.

Delayed planting in the autumn suppresses damage by take-all during the winter and often allows plants to escape severe damage. Take-all becomes most severe in fields with large amounts of crop residue on or near the soil surface (Cook and Reis, 1981). Removing residue by deep inversion tillage or burning the stubble reduces damage but is incompatible with techniques to control erosion. On irrigated fields, the incidence and severity of take-all are higher with small, frequent applications of water than with large, infrequent applications (Cook and Reis, 1981).

A microbially mediated suppression of severe take-all in annual wheat, named take-all decline (Asher and Shipton, 1981; Cook and Naiki, 1982), has led to strong interest in developing biological agents for controlling take-all (Thomashow and Weller, 1990; Bull et al., 1991; Cook, 1990, 1991b). The reliability and efficacy of biocontrol agents are improving, and some may become commercially available within the next decade. It is unclear whether they will be applied alone to the seed or soil, or combined with a fungicide seed treatment.

Rhizoctonia. Rhizoctonia root rot (caused by *R. solani* AG-8 and *R. oryzae*) limits the yield potential of both wheat and barley (Ogoshi et al., 1990; Smiley and Uddin, 1993). A chronic form reduces plant vigor without causing symptoms in the crop canopy. An acute form, called "bare patch" or "barley stunt," causes stunting, patchiness and severely reduced grain yield. The composition of *Rhizoctonia* species and strains is complex, which is reflected in the types of root tissue affected and the timing of such infections. For example, *R. solani* AG-8 is most damaging to crown roots in colder soils, while *R. oryzae* is most damaging to seminal roots in warmer soils and causes seedling damping-off (Mazzola et al., in press). Barley is more severely affected than wheat (Smiley and Wilkins, 1993) and spring plantings are often damaged more than autumn plantings.

Most rotational crops also are susceptible to infection by *R. solani* AG-8, but legumes, canola, and other noncereals appear to reduce the inoculum potential. Strategies that reduce soil erosion are especially favorable to Rhizoctonia root rot. The disease typically is most damaging in fields managed without tillage or with minimum tillage (Weller et al., 1986; Pumphrey et al., 1987). Complete burial of infested crop residue reduces damage in subsequent small grain crops, presumably by allowing seedlings to become well established before roots become heavily infected. Infections that sever root axes near the seed or crown are more damaging than those occurring further from the origin of the root axis.

As with take-all, banding fertilizer directly below the seed at planting increases the plant's tolerance of infection. The disease is not controlled adequately by fungicides or genetic tolerance, but as with take-all, may be reduced by long-term continuous cropping (Lucas et al., 1993; Smiley and Wilkins, 1993). Several soil-active herbicides predispose wheat to more severe damage from root rot (Smiley and Wilkins, 1992). Rhizoctonia root rot also becomes more severe when wheat or barley is planted only a few days after herbicides are used to kill weeds and volunteer cereals, compared with waiting two weeks or more (Smiley et al., 1992).

Pythium. Diseases caused by *Pythium* are widespread (Sprague, 1948; Cook et al., 1987) and include seed rot, seedling damping-off and browning root rot. *P. ultimum sporangiiferum* and *P. irregulare* are the primary species causing root rot (Chamswarng and Cook, 1985; Ingram and Cook, 1990). They frequently are isolated from the embryos of germinating seeds and from juvenile root tissues (Hering et al., 1987). Seed quality has a strong influence on seedlings' susceptibility to these diseases (Hering et al., 1987).

Pythium root rot is difficult to diagnose (Wiese, 1987), and affected plants are easily confused with nitrogen-deficient plants. Soil fumigation, solarization and fungicides were used to determine the importance of *Pythium* in the PNW (Cook et al., 1990; Cook and Haglund, 1991). Root rot is particularly severe in fields under minimum- or no-till management, especially when they are cropped annually and seeded late. Crop rotation is not useful for controlling this disease. Fungicides are available for suppressing seed rot and damping-off stages but are less effective against root rot (Cook and Zhang, 1985). Cultivars that can rapidly replace damaged roots apparently can better withstand debilitation caused by *Pythium*.

A root-infecting vascular pathogen

Cephalosporium stripe (caused by *C. gramineum*) causes severe damage to winter wheat and minor damage to winter barley, but none to spring cereals (Wiese, 1987; Cook and Veseth, 1991). This disease is especially damaging when plants become large in the autumn and are then exposed to a very cold winter. Root injuries, such as from freeze/thaw cycles or a high population of wireworms (Slope and Bardner, 1965; Martin et al., 1989; Specht and Murray, 1990), apparently enable *C. gramineum* to penetrate the vascular system of roots.

Crop and soil management strategies strongly influence the severity of Cephalosporium stripe (Cook and Reis, 1981; Christian and Miller, 1984; Wiese, 1987; Veseth et al., 1993). Planting in late autumn reduces infection by restricting coronal root development before winter, but also may delay plant development and reduce yield. The disease becomes severe in wheat fields in a two-year rotation with summer fallow. Excellent control is achieved when winter cereals are less frequent in the rotation, since *C. gramineum* survives only in undecomposed wheat tissue. A three-year

rotation (winter cereal, spring cereal or legume, and summer fallow) greatly reduces disease potential by limiting pathogen survival and sporulation.

Another effective control strategy is to reduce the amount of infected crop residue remaining near the soil surface (Mathre and Johnston, 1975; Wiese and Ravenscroft, 1975; Bockus et al., 1983). Inversion tillage, burning, and eliminating susceptible grassy weeds all are effective controls but may be harmful to the soil (Duff et al., 1993). Infection of roots by *C. gramineum* may also be reduced in no-till systems that increase snow retention and thereby insulate the soil from extremely low temperatures and reduce the number and magnitude of freeze/thaw cycles in the root zone. Acidification of soil by nitrogen fertilizer (Mahler et al., 1985; Rasmussen and Rohde, 1989) may aggravate Cephalosporium stripe possibly by enhancing the survival or virulence of the pathogen (Murray et al., 1992). Fungicides have not proven useful for controlling this disease. Sources of genetic resistance are known (Mathre et al., 1985) and attempts are being made to incorporate resistance into agronomically acceptable wheat cultivars (Roberts and Allan, 1990). Commercial cultivars differ in tolerance to infection by *C. gramineum* (Veseth et al., 1993).

Unspecific root-, crown-, and culm-infecting pathogens

A complex of unspecialized pathogenic fungi cause severe damage to wheat and barley throughout the region (Cook, 1981; Smiley and Patterson, 1995b). The complex includes *Fusarium culmorum*, *F. graminearum* Group I, *F. graminearum* Group II (=*Gibberella zeae*), *F. avenaceum* (=*G. avenacea*), and *Bipolaris sorokiniana* (=*Cochliobolus sativus*) (Sprague, 1948; Cook, 1968, 1980, 1981; Smiley and Patterson, 1995c). Fusarium foot rot is caused by species of *Fusarium*, common root rot is caused by *B. sorokiniana*, and dryland foot rot is an unspecific name for diseases caused by all these pathogens (Wiese, 1987). Although environmental conditions in the PNW usually confine infections to root, scutellum, subcrown internode, and crown tissues, some members of the complex also can infect the culm, leaves, and head.

Members of the complex all cause similar symptoms on small grains (Martens et al., 1984; Wiese, 1987; Sturtz and Bernier, 1989; Windels and Holen, 1989). Although it often is difficult to determine the dominant member, this distinction is important because the fungi vary in survival, pathogenicity, geographic region of dominance, and response to genetic, chemical and cultural control strategies. *F. graminearum* Group I (Francis and Burgess, 1977) occurs in unirrigated fields throughout the region, with *F. culmorum* the principal pathogen in some areas (Smiley and Patterson, 1995c). *F. graminearum* Groups I and II both occur in irrigated fields, and Group II is more prevalent when maize is included in the rotation. *F. avenaceum* is present throughout the region but dominates only in the coolest, wettest areas. *B. sorokiniana* is the least widely distributed member of the complex and appears to cause only very localized economic damage. *B. sorokiniana* and *Fusarium* spp. often appear together in individual plants.

Fusarium foot rot is most damaging under conditions that cause plant water stress between anthesis and maturation (Cook, 1981). Water stress may result from early seeding, high nitrogen fertility and high plant density (Papendick and Cook, 1974). *F. culmorum* survives freely in soil as persistent chlamydospores (Sitton and Cook, 1981). The principal infection sites for *F. culmorum* are the emerging crown roots and crown tissue wounded by emerging roots (Cook, 1968). Residue placement has little influence on the vertical distribution of chlamydospores in tilled soils. In contrast, *F. graminearum* Group I persists mostly as mycelium in host debris (Sitton and Cook, 1981). Therefore, the abundance and placement of infested straw in the soil profile influences its site of infection. The principal infection sites are the crown and basal stem in high-residue systems (subsurface blade) and the scutellum, subcrown internode, and lower crown in low-residue systems (offset disk or burn + disk) (Summerell et al., 1990). Damage from *F. graminearum* Group I is greatest with high amounts of residue and high nitrogen concentration (Smiley and Uddin, 1992).

Fungicides and genetic resistance are not available for suppressing Fusarium foot rot. However, cultivars of winter wheat exhibit modest differences in tolerance and can be used to reduce damage where the risk is highest.

Common root rot was among the earliest root and crown rots described in the region (Sprague, 1948), but it has not been investigated recently. The disease apparently is more damaging to barley than wheat, to spring- than autumn-sown cereals, and to cereals grown annually rather than in rotation with other crops or fallow. *B. sorokiniana* survives as spores in soil but also can be seedborne. It is not clear whether information collected mostly in regions with summer-dominant rainfall is applicable to farming conditions and climates in the PNW, where rainfall occurs mostly during winter.

Other Diseases

Viral diseases

Barley yellow dwarf is the principal viral disease of small grains in the PNW. Maize is an important oversummering host for the aphid vectors of this virus, and damage in small grain cereals is increasing as irrigated maize expands and winter wheat is planted earlier to reduce soil erosion (Bruehl, 1961; Wiese, 1987; Gildow, 1990). Management of barley yellow dwarf involves monitoring and reporting aphid populations weekly at multiple sites across the region (Pike et al., 1990), controlling volunteer plants to break the green bridge (Wiese, 1987), and planting as late as practicable during autumn to minimize exposure of young plants to high aphid populations (Wiese, 1987; Pike, 1990). Limited genetic tolerance is available among wheat cultivars. Registration of imidacloprid during 1995 as an insecticidal seed treatment provides additional promise for restricting transmission of this virus (Pike et al., 1993).

Wheat streak mosaic, which is vectored by the wheat leaf curl mite (*Aceria tulipae*), causes periodic damage in some areas of the PNW. Management of wheat streak mosaic primarily involves breaking the green bridge by eradicating volunteer wheat plants, and planting in late autumn to minimize exposure of young plants to high populations of the leaf curl mite.

Foliage diseases of unknown cause

Physiologic leaf spot is a disease of unknown cause that affects wheat (Smiley et al., 1993a,b; Engel et al., 1994). In heavily

affected fields, the disease may kill much of the flag leaf and all older leaves. Physiologic leaf spot is often incorrectly diagnosed as Septoria leaf blotch or tan spot. Crop damage can be reduced by growing wheat cultivars with low to moderate susceptibility and by planting as late in autumn as possible. Wheat is more severely affected when grown annually than in wheat-fallow, wheat-pea, or other rotations. Fungicides do not reduce the severity of physiologic leaf spot. Application of chloride fertilizer has suppressed this disease and improved grain yield in several regions.

Parasitic nematodes

Cereal cyst nematode (*Heterodera avenae*) occurs in several production regions of the PNW, where it can greatly reduce yields of winter or spring wheat cropped annually (Smiley et al., 1994). Crop rotations that space cereal crops at least two years apart reduce the nematode population and promote optimal yields if grasses and volunteer cereals are controlled throughout the rotation (Smiley et al., 1994). Genetic resistance (O'Brien and Fisher, 1974) is not available in wheat cultivars developed for the PNW, and nematicides are not registered for commercial use on small grains.

Lesion nematode (*Pratylenchus thornei*) also damages wheat and barley. However, little is known about its economic importance or management.

Integrated Management Strategies and Challenges for the Future

Fundamental aspects of etiology and epidemiology remain unknown for many diseases and must be determined before more precise disease management recommendations can be developed. Knowledge of microbial ecology also is being refined and will enhance the development of effective biological control agents (Cook, 1991b).

Crop residue and soil management strategies have a strong influence on wheat and barley diseases in semiarid regions of the PNW (Cook, 1968). High priority must be given to controlling diseases favored by conservation cropping systems and to smuts and rusts that require continuous oversight. Root, crown and culm diseases that may become highly damaging in minimum- or no-till cropping systems include Pythium root rot, Rhizoctonia root rot, and take-all. Cephalosporium stripe and Fusarium foot rot have a variable response to tillage systems, and eyespot and sharp eyespot often are more severe with inversion tillage. Stubble burning and inversion tillage often reduce disease risk but usually work against soil conservation practices. Further shifts in disease management presumably will occur as more straw is used in industrial processes.

Many diseases are strongly influenced by planting date. Diseases favored by early planting include barley yellow dwarf, Cephalosporium stripe, eyespot, flag smut, Fusarium foot rot, sharp eyespot, stripe rust, take-all and wheat streak mosaic. Diseases favored by late planting include common bunt, dwarf bunt, Pythium root rot, Rhizoctonia root rot and snow molds. The highly diverse climatic and soil conditions in the PNW, coupled with market considerations, make it difficult to recommend specific planting dates to control diseases and achieve maximum yield in each field and location. In general, late planting dates are unacceptable because they often increase soil erosion or reduce grain yield.

Much of the winter wheat in the region is produced in a wheat-fallow rotation. Disease management programs would become much more efficient if rotations could be lengthened by introducing profitable alternative crops. Three-year rotations with a single winter wheat crop are more effective than two-year rotations for reducing disease damage. However, climate, lack of adapted and profitable alternative crops, and economic factors have restricted this option. Long rotations generally are unpopular because they reduce wheat acreage and income from the wheat price-support subsidy. Spring wheat or barley are occasionally planted annually but are more prone to root rots than cereals rotated with fallow. Spring wheat following fallow or winter wheat generally produces about half the yield attainable with winter wheat in a two-year rotation with fallow.

Genetic resistance is available for smuts, rusts, eyespot and physiologic leaf spot. Cultivars also are available with limited tolerance to Cephalosporium stripe and Fusarium foot rot. There is increasing interest in cultivar mixtures or multi-lines to reduce the rate of disease epiphytotics. This approach to genetic diversification is particularly applicable to rusts and other polycyclic foliar diseases caused by pathogens that sporulate abundantly on surfaces of infected hosts during the growing season. Seed mixtures are used to balance high productivity with tolerance to winter damage; seeds of cultivars with each attribute are mixed before planting. New sources of genetic disease resistance will continue to be sought. Similarly, the description of wheat and barley genomes will enhance the development of improved cultivars.

Foliar-applied fungicides are used on less than 10% of irrigated and unirrigated wheat and barley in the semiarid regions of the PNW. Benomyl, propiconazole or triadimefon are applied as a curative for rusts and eyespot. Applications are influenced by disease potential (incidence and severity of current infection), stage of plant growth, projected yield and grain price, fungicide cost, and weather forecast. Usually, only a single fungicide application per crop gives an economic benefit, and multiple applications are rare. Although acceptance of cultivars with improved tolerance or resistance has further reduced the need for foliar fungicides, profitable production of small grains on some fields may always require periodic applications. Advances in controlling insect and mite vectors also will help reduce damage from viral diseases.

Recent advances in chemical control of wheat and barley diseases have focused mostly on improved seed treatments. Before carboxin was registered, newly released winter wheat cultivars became susceptible to new races of smut fungi within five years. During the past twenty years, most seed has been treated with carboxin alone or in combination with thiram, metalaxyl, imazalil, or quintozene (Smiley et al., 1990; 1991). Carboxin seed treatment has remained effective for smut control throughout the region. No localized resistance to the fungicide has been identified, but we do not know whether this stability will continue in view of recent releases of smut-susceptible cultivars in the region.

Two new seed treatment fungicides (difenoconazole and tebuconazole) were registered during 1994 and 1995. Compared with carboxin, difenoconazole improves seedling establishment, crop yield, and the spectrum of diseases controlled, and reduces

the amount of active ingredient applied by 80 to 90% (Smiley and Patterson, 1995a,d).

Disease management will undoubtedly become more refined as "precision farming" technologies become more refined and are practiced more widely. Fields previously were defined by dividing individual farmers' owned plus leased land into units of workable size managed uniformly, with little attention to soil depth, slope, aspect, and other factors affecting productivity. Parts of some fields are now being managed according to specific slope steepness or aspect, or other topographic or soil characteristics. Such practices include site-specific yield measurement, fertilizer application, cultivar selection and planting rate, and pest management. New technologies in global positioning, "on-the-move" equipment adjustments and environmental and pest monitoring are allowing these new practices to be developed for large and remote areas.

Finally, additional integration of all cropping systems information into computerized "expert" systems (Line and Cu, 1992) will continue to refine our understanding and control of complex interactions among hosts, environments, vectors and pathogens. These advances will enable farmers and advisors to customize the management of individual fields more skillfully.

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UPCOMING EVENTS

October 15–17, a grazier's class will be held at Michigan State University's Kellogg Biological Station, East Lansing; contact Teresa Miller, 525 S. Pine St., #207, Lansing, MI 48933; (517) 346-7427.

October 16, Fourth Annual Fertilizer Research and Education Program will be held in Modesto, CA; contact Kertrina Anderson or Casey Walsh Cady, California Department of Food and Agriculture, 1220 N St., Sacramento, CA 95814; (916) 653-5340.

October 16, "Turf & Golf Course Management," in Seal Beach, CA, and **October 17,** "Strawberries & Vegetables," in Encinitas, CA, will be sponsored by the Committee for Sustainable Agriculture; contact the Committee at (916) 756-6967.

October 18–21, "Natural Products Expo East" will be held in Baltimore, MD; contact Holly McGee, Natural Products Expo East, P.O. Box 671, Boulder, CO 80306-0671; (303) 939-8440 ext. 157.

October 20–26 and October 27–November 1, "Herbicide Action," an "intensive course," will be held at Purdue University, West Lafayette, IN; contact Kathy Hyman, (317) 494-2758; S.C. Weller, (317) 494-1333; or 1-800-359-2968, ext. 92H.

October 25–27, "Bioneers: Practical Solutions for Restoring the Earth" will be held in San Francisco, CA; contact Collective Heritage Institute, 369 Montezuma, #334, Santa Fe, NM 87501; (505) 986-0366.

October 26, "A Conference on Cancer and Pesticides" will be held at the Patuxent Research Refuge, Laurel, MD; contact the Rachel Carson Council, 8940 Jones Mill Road, Chevy Chase, MD 20815; (301) 652-1877; e-mail rccouncil@aol.com

October 31–November 1, "Forest and Woodland Resources for Sustainable Community Development" will be held in Fayetteville, AR; contact Donald E. Voth, Professor of Rural Sociology, Department of Agricultural Economics and Rural Sociology, University of Arkansas, A227, Fayetteville, AR 72701; (501) 575-2409; e-mail dvoth@comp.uark.edu

November 1–2, "Profit From Diversity," the Small Farm Seminars and Trade Show, will be held in Columbia, MO; contact Small Farm Today Magazine, Chuck DeCourley, 1-800-633-2535.

November 4–6, Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reduction will be held in Orlando, FL; contact Margie, Methyl Bromide Alternatives Outreach, (209) 244-4710.

November 4–15, "Community Supported Agriculture," a ten-day course, will be held at New Farms, HC 69 Box 62, Rociada, N.M. 87742; (505) 425-5457.

November 6–8, "21st Century Solutions: New Uses for Agricultural Products, and Biomass Workshop" will be held in Tulare, CA; contact Dr. Kennith Foster, University of Arizona, (520) 621-7900; e-mail http://ag.arizona.edu/OALS/NUC/NUCHome.html.

November 6–8, "Biofair: The Second World Trade Fair for Certified Organic Products" will be held in Costa Rica; contact AgriSystems International, 125 West Seventh St., Wind Gap, PA 18091; (610) 863-6700.

November 8–10, "Agriculture, Community, and Economy: Weaving a Sustainable Future," the Carolina Farm Stewardship Association's 11th Annual Sustainable Agriculture Conference will be held in Rock Hill, S.C.; contact Alyx Perry, CFSA, 115 W. Main St., Carrboro, N.C. 27510; (919) 968-1030.

November 11–17, "Maximizing Sustainable Rice Yields Through Improved Soil and Environmental Management" will be held in Khon Kaen Province, Thailand; contact Dr. Tasnee Attanandana, Soil and Fertilizer Society of Thailand, Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand; phone (662) 579-2028.

November 11–16, "Changing Agricultural Opportunities: The Role of Farming Systems Approaches" will be held in Colombo, Sri Lanka; contact Symposium Coordinator, Secretariat, P.O. Box 42, Socio Economics and Planning Centre, Peradeniya, Sri Lanka; phone 94-8-88798; e-mail Sympo@deptag.ac.lk

November 13–15, "Mapping the Future," the Composting Council's Seventh Annual Conference, will be held in Arlington, VA; contact the Council, 114 South Pitt St., Alexandria, VA 22314; (703) 739-2401.

November 14–17, "Seeds of Hope in a Changing Agriculture," will be held in St. Paul, MN; contact the Farmers Dialogue, 661 Western Ave., St. Paul, MN 55103; (612) 698-7382.

November 18–19, "Corporations, Conservation & Collaborations," the 8th Annual Symposium of the Wildlife Habitat Council, will be held in Washington, D.C.; contact the Council, 1010 Wayne Ave., #920, Silver Spring, MD 20910; (301) 588-8994; e-mail WHC@cais.com

December 5–7, Acres USA Conference will be held in St. Louis, MO; contact Acres USA, P.O. Box 8800, Metairie, LA 70011; 1-800-355-5313.

Insect pests and management technologies in dryland wheat in Washington

K. S. Pike and L. K. Tanigoshi

Abstract. *Six species of aphids (Homoptera: Aphididae) are the most economically significant insect pests of wheat in Washington. Management technologies under development or in use in Washington emphasize biorational approaches, including development and use of resistance germplasm, manipulation of pest populations through cropping systems, and development of biological controls. We review wheat yield losses caused by aphids, their biological control, and the effects of conservation tillage and systemic seed treatment.*

Key words: aphids, conservation tillage, biological control, natural enemies

Introduction

Washington's economic stability is linked to several key industries and agricultural commodities. Wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), pea (*Pisum sativum* L.), lentil (*Lens culinaris* Medik.), and selected grasses are the main dryland crops, and together account for a large fraction of the value of crops produced in the state. They are grown east of the Cascade Mountains in a region characterized by a wide range of elevations, habitats and precipitation zones (15 to 75 cm annually), and are affected by a complex of insects, mites, weeds, and diseases. Some dryland pest problems are accentuated because of nearby irrigated crops in central Washington that serve as additional pest reservoirs. The diversity and interrelationships of these pests and growing conditions increase the challenges of protecting the crops while sustaining the natural resources of the region. Team research, interdisciplinary collaboration, and global involvement by Washington State University scientists in dryland and irrigated cropping systems have become increasingly important in addressing pest problems.

Research on protecting dryland wheat from insects emphasizes the development and use of biological agents in concert with other economical management measures. The specific priorities are reviewed often and changed as needed as new pests, races, biotypes and farming practices emerge as part of an ever-changing agroecosystem. Of the insect pests that can significantly damage wheat in Washington, cereal aphids rank first, and are the focus of this discussion.

Damage from Cereal Aphids

Six major cereal aphids are common in wheat in Washington: bird cherry-oat aphid (*Rhopalosiphum padi* [L.]); corn leaf aphid (*Rhopalosiphum maidis* [Fitch]); English grain aphid (*Sitobion avenae* [F.]); greenbug (*Schizaphis graminum* [Rondani]); rose grass aphid (*Metopolophium dirhodum* [Walker]); and Russian wheat aphid (*Diuraphis noxia* [Kurdjumov]) (Pike et. al., 1991a). Some of these species are originally from central Asia, where they are usually held in check by climate and natural enemies.

Cereal aphids damage wheat by direct feeding, introduction of toxins, and the transmission of viruses, especially barley yellow dwarf virus. In Washington, two or more major species usually are present in a field, sometimes all six. Their population success or lack of success is linked to the current weather, changes in weather, and biotic and other factors.

Yield losses in wheat from aphids and aphid-transmitted viruses vary with variables such as secondary spread of aphids in fields following the initial entry of founder immigrants, the accumulated days of aphid feeding, the size and vigor of plants at the time of infestation, and the level of natural enemies. Recent field trials on winter wheat at Prosser, Washington, demonstrated how significant natural infestations of cereal aphids can be (Table 1). Bird cherry-oat aphid and rose grass aphid were the predominate aphids present. Paired plots, with and without aphids, were arranged in a randomized complete block design, with 9 replicates. Yields on plots without aphids were approximately double those with aphids.

Table 1. Effect of aphid and virus from natural infestation of cereal aphids on winter wheat, Prosser, Washington, 1992–93 crop year.[1]

Yield (kg/ha)	
With aphid virus	2936
Without aphid virus	5954
Value ($/ha)	
With aphid virus	404
Without aphid virus	819
Increase without virus	415

[1] Wheat valued at $0.1375/kg ($3.75/bu).

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Similarly, yields can be increased in spring wheat by limiting aphid infestations (Pike et al., 1993).

Aphid Management Technologies

The emphasis in aphid control is on biorationally based IPM approaches: development of a germplasm base with resistance to Russian wheat aphid and Hessian fly (*Mayetiola destructor* [Say]); evaluation of cropping systems' impact on pest populations and the possibilities for manipulating them; and development of biological controls as the primary approach or as a component with other approaches. Usually, two or more control approaches are employed, including: chemical fallow to eliminate volunteer wheat that hosts aphids in late summer; delayed fall planting linked to seasonal flight patterns (usually 1–2 week delay, but not too late to jeopardize stand establishment); plant spacing to reduce aphid landings in new plantings (dense stands are less attractive to incoming aphids); directed systemic insecticide that kills target aphids without directly affecting beneficial predators and parasitoids; use of thresholds to avoid unnecessary chemical applications; and timely transfer of information to growers on aphids' migratory flight.

Biological control

Cereal aphid predators and parasitoids play a significant role in controlling aphids in Washington, but the value of these natural enemies often is not recognized at the farm level. Studies are in progress to document the effectiveness of these natural enemies and their abundance across seasons and locations. The use of biological agents to control cereal aphids, especially Russian wheat aphid, in Washington and other western states has been of high interest and has led to several searches for natural enemies in Old World environments (Poprawski and Gruber 1988, 1989; Carl, 1989; Gonzalez et al., 1989; Halbert et al., 1989; Hopper and Mercadier, 1989; Pike and Tanigoshi, 1989; Pike et al., 1989; Hopper, 1992; Pike et al., 1992; Tanigoshi et al., 1995). Washington State University has been especially active in the Middle East because cereal aphid problems are infrequent there, a situation attributed in part to biological control (Tanigoshi et al., 1995). Most of the bioagents that have been collected, mass propagated, and released are parasitoids.

An international collaboration has characterized the biogeography and aphid habitats that sustain beneficials through the year in the arid and semiarid steppe grasslands and small grains of the Middle East and Morocco. Collaborators in this effort are Washington State University, the International Center for Agricultural Research in the Dry Areas (Syria), Cukarova University (Turkey), and the MidAmerica International Agricultural Consortium (Morocco) (Miller et al., 1993). These exotic biocontrol agents are expected to become established and have their maximum effect on target aphids in areas of Washington similar to the collection sites (Tanigoshi et al., 1995). The climate, habitat, precipitation, and temperature of Morocco, the lowlands and highlands of Jordan and Syria, and the Anatolian Plateau of south central Turkey are similar to those of the low rainfall zones of eastern Washington. To enhance current levels of biocontrol, scientific partnerships and continued discovery are needed to characterize indigenous and introduced species in Old and New World settings in elevation, cropping and intercropping systems, noncropping habitats, and climate.

The new Northwest Biocontrol Insectary and Quarantine facility (NWBIQ), developed by Washington State University's Department of Entomology and the College of Agriculture and Home Economics at Pullman, Washington, provides an opportunity to establish a large pool of natural enemies of Russian wheat aphid for use in biocontrol, and to expand research efforts on several biological fronts. The NWBIQ is one of five main centers in the United States where natural enemies of Russian wheat aphid are held live. Founder populations are available on request for research and applied use. Other centers with natural enemies of Russian wheat aphid are University of California, Riverside; Texas A&M University, College Station; USDA-ARS, Stillwater, Oklahoma; and USDA-APHIS, Niles, Michigan.

The large pool of live natural enemies maintained by the NWBIQ and others represents not only a commitment by U.S. scientists to use a complex of beneficial species to control cereal aphids, but also a broad international collaborative search and collection effort involving scientists from Argentina, Brazil, Chile, China, Czech Republic, France, Greece, Morocco, Portugal, Russia, Switzerland, Syria, and Turkey.

The 1993 growing season in Washington was the sixth year in which exotic bioagents of cereal aphids were mass produced and released. Over 500 thousand parasitoids were reared at the NWBIQ and released in 1993. Of these, 55% were released into wheat, 10% into barley, 17% into conservation reserve and wildlife management sites, and 18% into other noncrop habitats. An additional 200 thousand parasitoids were produced through on-farm rearings in 1993 as part of a pilot project to accelerate field establishment. Since 1988, more than 2.2 million natural enemies (parasitoids and predators) of grain aphids have been released at more than 200 sites in Washington (Fig. 1). Several released parasitoids (*Aphelinus albipodus* Hyatt & Fatima, *Aphelinus asychis* Walker, *Aphidius colemani* Viereck, and exotic *Diaeretiella rapae* [M'Intosh]) are established at one or more locations. Their rates of parasitism vary, but some have reached levels of 80–100% in spring populations of Russian wheat aphid, preventing it from reaching economically significant levels. These parasitoids also are attacking other aphid pest species. Besides the parasitoids, an exotic predator, *Coccinella septempunctata* L., is now established.

Cereal aphid flight

Aphid suction traps operated during the growing season in Washington from 1986 to 1993 have been an effective tool in monitoring and assessing regional flight activity. Trap records accumulated over several years are a useful database for defining the seasonal and annual composition of the aphid aerofauna (Pike et al., 1991b) and flight patterns. These data are also useful in determining the time and location of aphid trouble spots, assessing the significance of incoming trap catches by comparison with previous years' records and crop infestations, determining areas for release of needed biological agents, projecting future activity, and detecting new species or species new to the region. For example, Russian wheat aphid was first detected in the region by suction trap (Halbert et al., 1987). Informational releases based on traps have

Figure 1. Release sites of insect parasitoides and predators of Russian wheat aphid and other cereal aphids in Washington, 1988–1993.

helped growers learn what action, if any, is needed to control aphid pests in their area.

Conservation tillage

Conservation tillage has not noticeably affected populations of bird cherry-oat aphid, corn leaf aphid, rose grass aphid or Russian wheat aphid in wheat, but it can affect greenbug and English grain aphid. In experimental trials by Burton and Krenzer (1985), greenbugs were less abundant in wheat grown with moderate to high surface residues than with clean cultivation. The reason is not fully understood, but crop residues, acting as a reflective mulch, may repel or mask the crop's ability to attract settling greenbugs. English grain aphid, in contrast, can be more abundant under conservation tillage than conventional tillage (Borden, 1991). However, an increase does not necessarily mean that this aphid will reach an economic injury threshold. In most years, English grain aphid does not damage crops extensively. With few exceptions, the abundance of aphids and other pest insects or mites has not changed substantially during more than a decade of conservation farming in the Northwest. The few arthropod problems that are enhanced by conservation tillage are manageable and are more than offset by the gains in soil moisture retention and soil erosion control.

Systemic seed treatment for aphid control

A new insecticide, Gaucho (1-[(6-chloro-3-pyridinyl)methyl]-4,5-dihydro-*N*-nitro-1-*H*-imidazol-2-amine; nitroguanidine class chemistry; common name, imidacloprid), has been extensively evaluated for use as a seed treatment in wheat to control aphids. In field and greenhouse trials in Washington and Oregon, it controlled aphids and increased yields 33 to 94% over untreated wheat (Pike et al., 1993). It can be used with little hazard to nontarget organisms, such as beneficial insects, and is compatible with seed fungicides.

Future Direction

Washington's dryland wheat industry is moving toward managing aphids with more natural pest control alternatives. Continued research will be needed for greater understanding of biological processes and further achievements in effectively integrating biological, cultural, and other controls with emerging sustainable wheat cropping systems. Washington State University is expanding its NWBIQ facilities to enhance mass propagation of beneficial natural enemies for classical field augmentation and evaluation research, molecular technologies

for systematically understanding speciation, and development of landscape ecology methods supportive of biological solutions for continued economical wheat production.

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Three Awards Programs Request Nominations

Three agricultural awards programs are requesting nominations for their awards.

The World Food Prize Foundation requests nominations for the 1997 World Food Prize, which recognizes outstanding individual achievement in improving the quality, quantity, or availability of food in the world. The Prize emphasizes the importance of a nutritious and sustainable food supply for all people. Nominees should be individuals who have worked successfully toward this goal in any field involved in the world food supply, including agricultural science and technology, nutrition, social sciences, and other related fields.

For a brochure detailing the nomination process, contact The World Food Prize Office of the Secretariat, David Acker, College of Agriculture, Iowa State University, Ames, IA 50011-1050; (515) 294-8454; e-mail bjelland@iastate.edu or http://www.netins.net/showcase/wfp

The Oberly Award is given in odd-numbered years for the best English language bibliography in the field of agriculture or related science. Nominations may be made in the form of the bibliography and a letter, which should point out the reason the bibliography should be considered. Send nominations by December 1 to JoAnn DeVries, Oberly Jury Chair, University of Minnesota, St. Paul Campus Central Library, 1984 Buford Ave., St. Paul, MN 55108.

American Farmland Trust seeks nominations for its first annual Steward of the Land Award to recognize efforts by an individual farmer or farm family in land stewardship, agricultural conservation policy, or the use of sustainable farming practices. For a brochure and nomination form, contact AFT, 1920 N St., #400, Washington, D.C. 20036; (202) 659-5170, ext. 7130.

Fertility management in dryland conservation cropping systems of the Pacific Northwest

Paul E. Rasmussen

Abstract. *The Pacific Northwest dryland region is moving toward conservation tillage to control excessive erosion on steep slopes, but progress has been slow because of adverse effects on plant growth and yield. Fertility relations in cereal grains with conventional tillage are well known, with deficiencies occurring for nitrogen, sulfur, and phosphorus, in declining order of frequency. N and S deficiencies are more severe in conservation tillage, although the pattern of crop response to nutrient application is the same as in conventional tillage. Placing nutrients in a subsurface band near the seed is more effective than broadcasting on the surface. Higher fertility is required near developing root systems to offset greater competition from grassy weeds and more intense pressure from root-pruning soil pathogens. Conservation tillage alters soil fertility and plant growth in different ways on different landscapes. These differences must be considered to ensure that conservation tillage will be effective over the entire field.*

Key words: dryland cropping, conservation tillage, soil fertility

Limitations on Conservation Tillage in the Pacific Northwest

The Columbia Plateau of the Pacific Northwest has gently to steeply sloping topography that is very susceptible to erosion under conventional tillage (Papendick and Miller, 1977). The region's cereal yields are high because of favorable winter rainfall and an abundance of medium-textured loessial soils with high water storage capacity. Conservation tillage systems that control erosion have not been widely adopted because crop yields often have been 5 to 15% lower than under conventional tillage. This reduction has variously been attributed to increased disease incidence, greater weed infestation, higher nutrient immobilization, and slower plant development.

The topography of the Northwest is another reason for low adoption of conservation tillage because it is more diverse than in other regions of the world (Mulla, 1986). Soil fertility and nutrient deficiencies are altered with the change in environment caused by conversion to conservation tillage. Inconsistent plant responses occur when a single tillage system is applied to large fields. Different placement and variable rates of fertilizer are often required to reduce plant disease, alleviate plant stress and attain optimum yields. This paper summarizes fertility relations in Pacific Northwest dryland agriculture and discusses changes that result from adoption of conservation tillage.

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Conventional Tillage: Factors Affecting Soil Quality and Crop Growth

Soil organic matter and water

Because of the precipitation pattern, this region is best suited to winter or cool season spring crops, such as wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), peas (*Pisum sativum* L.), and lentils (*Lens culinaris* Medik). Nearly 70% of the precipitation is received between September 1 and March 31. Most crops in winter-rainfall climates are sensitive to delayed spring growth because they normally have a very high precipitation deficit during late stages of crop growth. Summer rainfall is inadequate for warm season crops such as corn (*Zea mays* L.), sorghum (*Sorghum vulgare*), or potatoes (*Solanum tuberosum* L.). Summer fallow is routine where annual precipitation is less than 425 mm because of greater yield stability and less risk of crop failure from drought.

However, frequent fallowing generally accelerates the depletion of soil organic matter (SOM) because little C is added during the fallow year, while biological oxidation of existing C continues at the same rate as in cropped soil, or even higher (Campbell et al., 1990; Collins et al., 1992). It is extremely difficult to prevent a continuing decline in SOM in a conventionally tilled wheat/fallow rotation (Fig. 1). Rotations that eliminate fallow therefore are desirable for soil quality, but in zones of very low rainfall, fallowing stabilizes crop yields and often makes crop production more profitable.

Including green manures in crop rotations increase N input but does not normally enhance C or N storage in soil (Power, 1990). Immature green residues contain low amounts of lignin and complex cellulose that favor C stabilization in SOM. Rotations that include legume hay production increase the amount of N recycled through crop residues, but there is usually little net addition of C or N to soil when the hay is harvested. Benefits to SOM, if they occur,

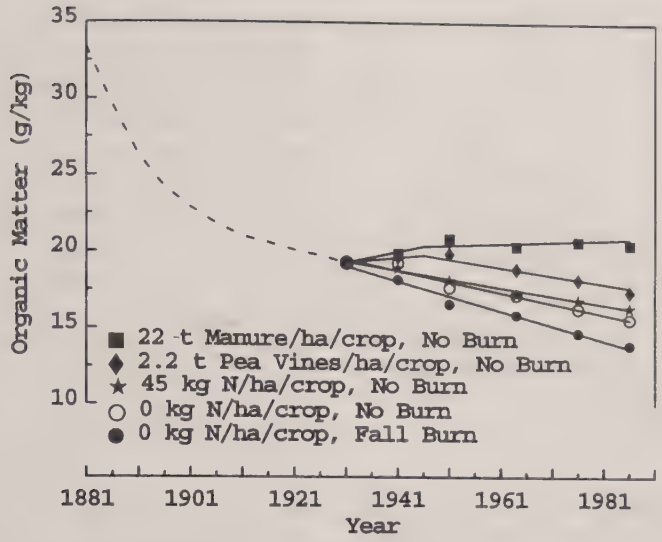

Figure 1. Crop management effects on soil organic matter in the 0 to 30 cm zone of a winter wheat/fallow rotation, 1931–1986; Pendleton, Oregon. Adapted from Rasmussen and Rhode, 1989.

are probably attributable to a substantial reduction in tillage and a decrease in erosion.

Winter cereals are normally seeded in September or October and harvested in July or August. Spring cereals and legumes are seeded in March or April and harvested in July or August. The highest yielding cereal varieties are typically those with the least winter dormancy and the fastest spring growth rates. Early seeding dates tend to increase crop yield, but can increase the severity of soil-borne diseases.

Regression equations show that winter wheat typically requires 100 mm of available water to produce the vegetative portion of the plant. Each mm of available water (stored soil water plus growing-season rainfall) above this amount will produce about 17 kg/ha of grain (Leggett, 1959). Soil storage of fall and winter precipitation typically averages 75% of the total received when land is in fallow wheat stubble, or 50% when seeded to winter wheat (Ramig and Ekin, 1991). Summer fallow soil will typically lose 25 mm of stored soil water and conserve none of the precipitation received between April and October.

Crop residues are essential for maintaining SOM in dryland farming systems, with greater residue input generally increasing SOM in the Pacific Northwest (Smith and Elliott, 1990; Rasmussen and Collins, 1991). The response is similar to that in other areas of the world (Powlson et al., 1986; Campbell et al., 1990; Paustian et al., 1992; Carter et al., 1993). All studies strongly suggest that returning adequate residue to soil is imperative for stabilizing or increasing SOM in semi-arid regions. Table 1 gives an example of the effect of residue input on SOM in a 275 mm rainfall zone of eastern Washington. Usually, more than the present amount of residue production is needed to stabilize SOM in any crop rotation that includes fallow. Thus, wheat/fallow rotations under conventional tillage and crop/livestock systems that use most of the crop residue for feed or fuel appear to have little chance of maintaining SOM in semi-arid regions.

Cultivation accelerates the oxidation of organic matter (Doran, 1980; Rasmussen and Collins, 1991). Grassland soils lose organic matter rapidly, with 25 to 40% being lost in the first 50 years of cultivation. Most soils have now been cultivated for 100 years and contain only about half the original SOM. The effects of cultivation on nutrient cycling probably are not uniform across the landscape (Power, 1990).

Soil erosion can be the major reason for loss of SOM (Voroney et al., 1981). SOM is highest near the soil surface, the part that is eroded by sheet and rill erosion. Wind erosion preferentially removes the clay and silt fractions, which contain most of the SOM. Organic C and P, total N and S, and mineralizable N all decrease with increasing erosion (Verity and Anderson, 1990). An annual erosion rate of 11 t/ha generally removes more C and N from the system than can be replaced by natural soil-forming factors.

Fertilizers and nutrient deficiencies

Nutrient applications that increase crop residue production generally enhance SOM levels, provided the residues are incorporated into the soil. The value of fertilizer and organic residues for organic matter in semi-arid soils was recognized many years ago (Smith et al., 1946). N fertilization normally increases straw production (Rasmussen and Rohde, 1988; Smith and Elliott, 1990) and promotes C and N retention in soil (Fig. 2). P and S play a similar but less dramatic role, but only because they are not as deficient as N and have less effect on dry matter production.

N is by far the most deficient nutrient for all nonlegume crops in the dryland Columbia Plateau. N application increases cereal yield in most precipitation zones on soils with low residual N. The response usually correlates with the degree of deficiency. Thus, N will increase yield more than S, P, K, or micronutrients. Nutrient interactions can change this pattern, but only the interaction between N and S is routine in dryland cereal production. N application can intensify S deficiency and actually decrease yield in cases of severe S deficiency.

Table 1. Effect of returning wheat straw on soil organic matter (SOM) and soil N in semiarid soil near Lind, Washington, 1922-1940.[1]

Straw Return Rate[2] (kg/ha)	Gain or Loss in SOM (kg/ha)	Gain or Loss in Soil N (kg/ha)
0	–2685	–381
896	–562	–240
1792	886	–186
3584	1326	–11

[1] Adapted from Smith et al. (1946), as revised by Smith and Elliott (1990).
[2] The amount of residue applied during the fallow year.

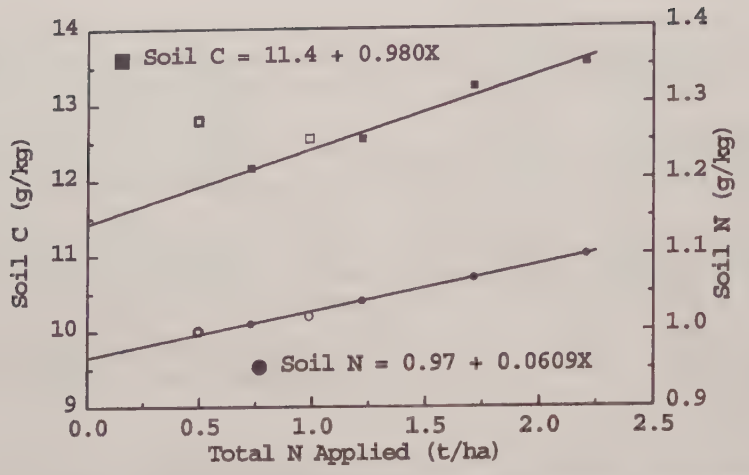

Figure 2. The effect of long-term application of N fertilizer in the 0–22 cm soil zone. Nitrogen applied between 1952 and 1984 at rates ranging from 0 to 180 kg N/ha per crop. Adapted from Rasmussen and Rhode, 1988.

N response is influenced by precipitation level, soil depth, previous crop, and residual soil N. There is high yearly variability in the amount of N needed to attain optimum yield (Table 2), which affects both economic return and environmental quality. Cereal yield and grain protein response to N are especially sensitive to the amount of precipitation received during the growing season (Fig. 3). Wheat responds more to N on deep than on shallow soils, and N applied beyond the crop's need is less detrimental to yield (Table 3). Soil testing for moisture and available N in the spring of the crop year provides a reasonable estimate of potential yield and N need (Leggett, 1959; Fiez et al., 1994a).

The previous crop grown also affects wheat yield strongly (Table 4), generally because of its effect on soil water and N availability. Green manures are a good source of N where precipitation exceeds 400 mm, but they can reduce the yield of the following crop in drier environments because they use stored soil water. Green manures can supply from 50 to 100 kg N/ha. Legume residues supply about 35 kg of N per ton of residue. Mineralization of SOM during one year of summer fallow supplies approximately 0.12 kg N/ha per mm of average annual precipitation. The amount mineralized is related to average precipitation level because SOM is linearly correlated with annual precipitation.

In conventional tillage, N can be either broadcast or banded with equal efficiency. Most fertilizer N presently is applied as anhydrous or aqua ammonia because these are cheaper. It is shanked 10–15 cm deep with 30–40 cm shank spacing. In general, N is used most efficiently when it is applied at seeding. In zones with annual precipitation below 350 mm, N can usually be applied in mid-fallow without significant loss through leaching or denitrification. In higher rainfall areas, efficiency is improved by reducing preplant N and applying more in the spring of the crop year (Sowers et al., 1994).

Sulfur is the second most deficient nutrient, but deficiency is rarely found in the field because farmers usually apply S if they even slightly suspect a deficiency. S deficiency is difficult to predict because soil and plant tissue tests are not highly accurate (Rasmussen and Kresge, 1986). Cereal grains generally do not respond to S on soils in low rainfall zones that have a calcareous horizon within 75 cm of the soil surface, since this layer is high in available S (Rasmussen and Kresge, 1986). Cereal grains occasionally show symptoms of S deficiency at an early growth stage, but the symptoms will disappear after the roots extend into the calcareous layer.

Cereal crops require about 1 kg of S for every 16 kg of N. Application of S at 12 to 20 kg/ha is common over much of the region. Residual availability of applied S is high where annual precipitation is less than 400 mm; 10 to 20 kg/ha often is adequate to meet the needs of two succeeding crops (Rasmussen and Kresge, 1986). Brassica crops such as Canola and other oilseed rapes (*Brassica napus* L.) and yellow mustard (*Synapsis alba)* require 3 to 10 times as much S as do cereals with the same yield, but sensitivity to S deficiency varies among varieties (Mahler et al., 1993). S is applied most commonly as ammonium thiosulfate or ammonium polysulfide during N application. S also can be applied as gypsum, ammonium phosphate/sulfate, or ammonium sulfate, which are equal in availability to the above materials but are more expensive.

Table 2. Yearly variation in the rate of N producing the optimum grain yield of winter wheat, winter wheat/fallow rotation, 1963-1987, Pendleton, Oregon.

	N Rate (kg/ha)[1]				
Year	0	45	90	135	160
	Grain Yield (t/ha)				
1963	2.4	4.2	3.7	2.8	2.5
1965	4.2	4.3	4.8	4.8	4.6
1967	2.8	4.1	3.6	3.0	2.6
1969	3.6	3.7	3.6	3.0	2.9
1971	3.4	5.3	5.7	5.2	4.5
1973	3.2	3.7	3.3	2.8	2.8
1975	3.4	4.5	4.0	3.8	3.8
1977	3.2	3.6	3.3	3.1	3.0
1979	2.8	3.8	3.7	3.0	3.3
1981	3.7	6.0	6.7	7.0	6.7
1983	2.8	4.2	5.8	6.5	6.2
1985	3.2	3.4	3.7	3.8	3.8
1987	3.8	5.3	5.6	5.0	4.8

[1] Underlined yields are at the N rate producing optimum grain yield.

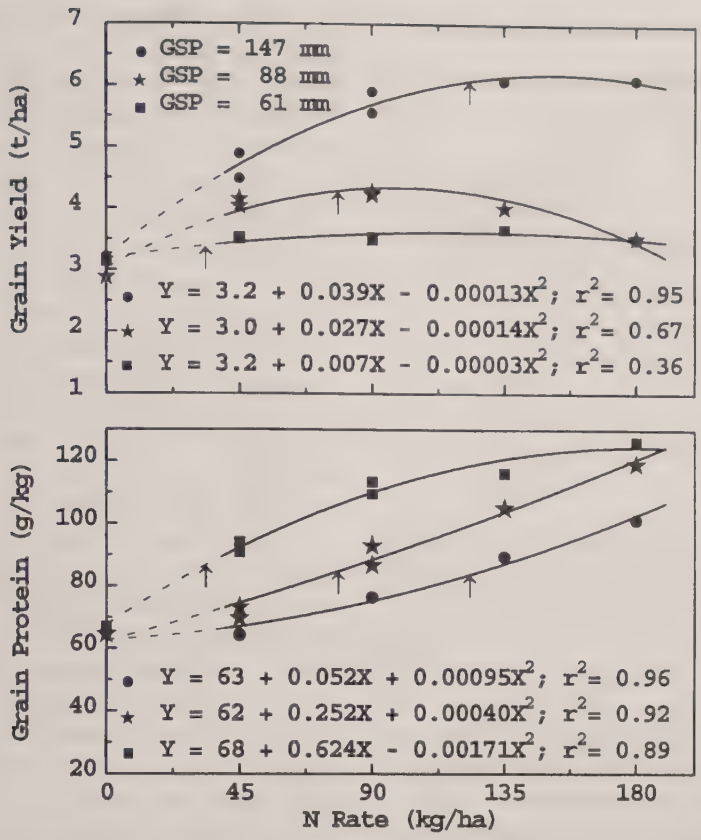

Figure 3. White winter wheat grain yield and protein response to applied-N under different growing-season precipitation (GSP) levels. All regressions significant at P=0.01. Adapted from Rasmussen and Rhode, 1991.

Table 3. The effect of soil depth and growing-season precipitation on winter wheat response to N in a wheat/fallow rotation, 1967-1987, Pendleton, Oregon.[1]

Soil Depth (cm)	Growing Season Precipitation[2] (mm)	Grain Yield (t/ha)		Optimum N Rate (kg/ha)	Net Return from N Application[3] ($/ha)	
		No N	Opt. N		Stand. Rate	Opt. Rate
210	109	3.29	5.78	123	266	266
	84	3.02	5.04	78	206	225
	58	3.09	4.10	67	76	100
120	109	3.56	5.31	90	171	185
	84	3.02	4.44	39	128	165
	58	3.16	3.63	34	6	45

[1] Adapted from Rasmussen and Rohde, 1991.
[2] April 1 to June 30 precipitation; values are the average of 4, 4, and 3 years for each precipitation level, respectively.
[3] Wheat valued at $128.60/t; N application cost $0.441/kg. Standard rate = 120 kg N/ha per crop; optimum rate determined from N rate response curve.

Phosphorus is the third most frequently deficient nutrient in dryland regions. Application of P can increase retention of tillers and hasten maturity. P deficiency in cereals is affected very little by tillage and frequency of cropping, but becomes more prevalent with higher crop yield (Rasmussen and Douglas, 1992). It occurs more on upper slope positions where most of the topsoil has been lost through erosion (Pan and Hopkins, 1991). Band placement of small amounts of P plus ammonium-N with or near the seed in cool wet environments often enhances plant development and is more efficient than broadcasting.

Deficiencies of K, Zn, Mo, and B are rare in dryland cropping. Mo and B are more likely to be deficient in legumes than in cereals. Potassium chloride application will sometimes increase yield in higher rainfall zones, especially when a cereal follows a cereal. Chloride deficiency is suspected, but the response may be affected by bacterial and fungal diseases.

Adopting Conservation Tillage: What Changes Can We Expect in Soil Fertility and Plant Development?

Soil organic matter. Tillage that retains more residue on or near the soil surface tends to conserve more SOM than burying the residue (Rasmussen and Collins, 1991). The biochemical environment of no-till soils is less oxidative than in conventionally tilled soil (Doran, 1980). Most of the increase in SOM with conservation tillage occurs in the upper 10 cm, with SOM at deeper depths about the same as in conventional tillage.

Crop growth. Conservation tillage tends to slow early spring growth of crops because the soil is colder than in conventional systems. Most of the temperature difference occurs from March to May because the residue mulch keeps the daily maximum from rising as high as in bare soil (Parsons, 1984; Pan et al., 1991). This especially affects cool season crops that must complete most of their growth before the onset of high summer temperature. Poorly drained soils and landscapes that receive less direct sunlight also tend to have delayed plant development under conservation tillage. Some plant pathogens are more damaging in colder soils (Cook, 1990; Cook and Veseth, 1991). Wheat seedlings grown in mulch tillage often are spindly, distorted, yellow, or stunted, and have poorly developed roots. Lower wheat yield with mulch tillage or direct drilling often is associated with increased root pathogen activity favored by cool, wet soil and an abundance of straw that serves as a food for the pathogens (Cook, 1990). Poor performance in residue does not appear directly related to fertility; this may be because the root system is unable to absorb sufficient quantities of nutrients even when they are present.

Table 4. Effect of previous crop on winter wheat grain yield as affected by precipitation zo ne and applied N.[1]

	Precipitation Zone and N Rate		
	395 mm	445 mm	
Previous Crop	0 N	0 N	45 kg/ha
Fallow	3.02	2.76	3.49
Green Manure	2.89	3.49	3.90
Peas	2.08	2.62	3.16
Wheat	0.67	1.34	2.28

[1] Adapted from Rasmussen et al., 1989.

Nutrient accumulation in soil. Conservation tillage systems tend to stratify most soil nutrients, leaving much higher concentrations near the soil surface than in plowed soil. This interferes with the plant roots' access to nutrients and creates problems in obtaining a soil sample that represents actual nutrient availability.

Conservation tillage systems also make the surface soil more acidic in higher rainfall zones (Mahler and Harder, 1984; Rasmussen and Rohde, 1989). Deep cultivation in conventional systems makes pH nearly uniform throughout the 20 cm tillage zone. With conservation tillage, pH is much lower in the upper 10 cm of soil than in conventional systems but higher in the 10 to 20 cm zone. Liming may be more important in conservation tillage to alleviate undesirable plant pathogen activity in the seed zone. Some plant diseases, such as Cephalosporium stripe, are more virulent in acidic soils and can be more damaging in conservation tillage when soil pH is allowed to decrease.

Nutrient deficiencies. Deficiencies of both N and S are more severe in no-till than in conventional tillage (Table 5). Conservation tillage systems that increase water storage and allow more frequent cropping are more likely to have S deficiency. P deficiency, in contrast, is not highly affected by tillage or frequency of cropping because P comes mainly from inorganic rather than organic sources.

Placement of fertilizer. Proper fertility management is much more critical in conservation tillage because of the potential for nutrient immobilization, less efficient roots, and the need to compensate for delayed spring growth. Because of plant performance problems associated with surface residues, broadcast application of fertilizer is less efficient in conservation tillage. N immobilization can be substantial. Subsurface banding with or near the seed improves the performance of both cereals and legumes (Koehler et al., 1987). Improved performance with banding is much greater for a cereal following a cereal than following a noncereal or fallow. Banding also is more critical for spring than for winter cereals.

Subsurface placement of N substantially reduces the competition of grassy weeds for water and nutrients (Reinertsen et al., 1984; Anderson, 1991). Fertilizer-seeding operations that disturb the soil directly below the seed may reduce the intensity of root-pruning diseases caused by Rhizoctonia and Pythium (Cook and Veseth, 1991). Chronic subclinical levels of root-pruning diseases normally are more prevalent in conservation tillage, especially no-till, and are suspected as the major cause of poorer cereal growth (Cook, 1990).

Banding fertilizer with or near the seed improves the plant's access to nutrients during early growth. Stress created by poorer root systems in conservation tillage prevent wheat plants from initiating tillers (Table 6). Missing tillers may be replaced by tillers that develop later, but these have lower yield potential because of their smaller root systems and later maturity. Proper placement of fertilizer also speeds development of the plant, which helps to offset delayed spring growth in conservation tillage caused by cooler soil. However, banding cannot compensate for poorer tiller initiation caused by the low light intensity associated with high surface residues.

Although banding improves plants' access to nutrients during early spring growth compared with broadcasting, it may reduce availability late in the season. When early plant development is not impaired and application rates are marginal for optimum yield, full-season availability may be less with banding, and yield somewhat lower. This may be why some people claim that more fertilizer is required in conservation tillage than in conventional systems. Band placement of fertilizer requires special equipment (Hyde et al., 1987). There are several specialized drills that band fertilizer and seed in one operation.

Placing too much fertilizer with or near the seed can reduce the stand and delay seedling emergence. High ammonium-N concentration creates free ammonia in the soil system, which kills seedlings and reduces the stand. Most N and S fertilizers also have a high salt index that can reduce the plant growth rate and increase the time required for seedlings to emerge. Toxic effects of fertilizer are much more pronounced

Table 5. Winter and spring cereal grain yields (t/ha) in no-till and conventional tillage as affected by level of fertility, 1983-1988, Pendleton, Oregon.[1]

	Winter cereal			Spring cereal		
Fertilizer[2]	NT[3]	CT[4]	NT/CT[5]	NT	CT	NT/CT
None	1.19	2.07	0.57	1.54	2.49	0.62
N	2.58	3.34	0.77	2.46	3.37	0.73
N + S	3.65	4.12	0.89	3.79	3.88	0.98
N + S + P	3.98	4.70	0.85	4.46	4.18	1.07

[1] Adapted from Rasmussen and Douglas, 1992.
[2] Average application rates (kg/ha): 109 N, 18 S, and 11 P.
[3] NT = No-Till
[4] CT = Conventional Tillage
[5] NT/CT = Ratio between no-till and conventional tillage yield

Table 6. Winter wheat plant development at late tillering (April 25) as affected by tillage and surface residue.[1]

Growth Feature	Conventional Tillage	No-till	
		Flailed	Burned
Plants/m^2	232 (28)[2]	193 (28)	212 (22)
Dry matter (g/m^2)	38 (3.8)	15 (1.9)	26 (5.2)
Height (cm)	49 (4.1)	38 (4.7)	47 (4.5)
Leaves per plant	7.5 (0.3)	6.6 (0.4)	7.0 (0.3)
T_0 (%)[3]	58 (2)	10 (1)	11 (1)
T_1 (%)	95 (1)	66 (2)	89 (3)
T_2 (%)	98 (2)	72 (5)	89 (1)
T_3 (%)	70 (4)	33 (26)	35 (11)
T_4 (%)	7 (7)	41 (19)	26 (2)
Culms per plant	4.3 (0.1)	3.3 (0.5)	3.5 (0.1)

[1] Adapted from Rasmussen, 1993.
[2] Number in parentheses is standard error of mean.
[3] T_0, T_1, T_2, T_3, and T_4 indicate the percentage of plants that have coleoptilar, first, second, third, and fourth tillers, respectively.

in warm, dry soil than in cool, wet soil. To avoid problems, no more than 15 kg/ha of N plus S plus K should be placed with oilseed crops, 10 kg/ha with large-seed legumes, and 25 kg/ha with cereal grains. P fertilizer placed with the seed generally causes harm only when applied at a high rate or when it includes ammonium-N.

Fertilizer generally does no harm if it is placed at least 5 cm from the seed. It is preferable to place it 5–7 cm below seed level when it is not banded directly below the seed. Early seminal roots of cereals grow downward at a 45° angle for 5 to 7 cm before turning vertical (Klepper et al., 1983). Fertilizer placed to the side of the seed at the same depth will be unavailable until the plant develops crown roots (the 4 to 5 leaf stage). By then, the first and second tillers should have been produced, but may not have been if the fertilizer is not in position to be available.

Landscape effects. Landscape plays an important role in the success of conservation tillage in the Pacific Northwest. Fields usually include slopes from 0 to 40% facing in all directions. Crop yield varies widely across the landscape, depending on slope steepness, aspect, shape, and degree of erosion (Mahler et al., 1979; Ciha, 1984; Douglas et al., 1984; Miller et al., 1988; Verity and Anderson, 1990; Fiez et al., 1994b). The landscape varies considerably in the soil's ability to store precipitation and mineralize N. This contributes to high variability in yield and fertilizer response. We have little information to predict how yields and fertilizer needs will change if entire fields are converted to conservation tillage. Steeply sloping portions of the upper landscape tend to benefit most from conservation tillage because of increased water infiltration. Because of lower soil temperature, the development of winter cereals may be poorer on steep north slopes converted to conservation tillage. This is true also for poorly drained soils on toeslopes and footslopes that are highly prone to diseases and weed infestations. These areas also have less need for conservation tillage to control wind or water erosion.

Summary

Widespread adoption of conservation tillage in Pacific Northwest dryland regions is slow because cereal yields often are lower than with conventional tillage. But change must come because soil erosion is excessive over much of the landscape and eventually will reduce yield. The primary challenge is to identify the reason for reduced yield in conservation tillage; it appears to be the combined result of changes in fertility status, disease pressure, and slower crop growth. Changes in nutrient deficiencies with adoption of conservation tillage are not dramatic. Deficiencies of N and S are more severe, and more frequent if increased water conservation permits more frequent cropping. The main change needed in fertilization practices is more precise fertilizer placement to overcome lower nutrient availability. Lower availability results primarily from immobilization of N by surface residues and from decreases in plant root density and function from increased bacterial and fungal pathogen pressure and lower soil temperature.

The current challenge is to identify what part of the landscape needs conservation tillage. Fields presently have a wide range in yield potential, water storage, response to fertilizer, and erosion. It is unlikely, however, that the entire landscape needs conservation tillage; ridgetops and shoulders should be targeted first. Accurate assessment of changes arising from converting a whole field to conservation tillage probably must wait until accurate yield monitors are developed for combines and detailed yield maps are constructed from several years of data collection.

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GIS and simulation technologies for assessing cropping systems management in dry environments

Claudio O. Stockle

Abstract. *The long-term productivity, sustainability, and environmental impact of cropping systems cannot be assessed adequately using conventional agronomic experiments. This paper discusses the use of computer-based technologies as support tools for this type of assessment, including crop growth simulation models, weather generators, geographical information systems, and risk assessment and economic models. Comprehensive systems that integrate these technologies are just emerging, offering great potential for the analysis of agricultural systems in the future.*

Key words: crop growth, models, geographical information systems, weather generators, regional analysis, agricultural systems

Introduction

Agricultural research institutions throughout the world face the problem of describing and characterizing their agro-regional ecological environments. This characterization is important to define the variability of environmental conditions in time and space and to identify the biophysical constraints to crop production and resource management. This characterization allows scientists to set research priorities, target breeding programs, search for alternative soil and crop management schemes, and guide the process of technology transfer.

Besides research applications, the assessment of long-term productivity, sustainability, economic feasibility, and environmental impact of a region's agricultural systems is important for management, planning, and policy making. Evaluation of risk also is very important, particularly in dryland regions with low and erratic precipitation.

Agronomic experimentation is the standard avenue for cultivar selection and the evaluation of crop response to weather, soil, and management options. However, agronomic experiments often are limited by the availability of resources. Thus, they are usually conducted for only a few sites and conditions and for a short time, typically three to four years. On the other hand, a suitable analysis of agricultural productivity and sustainability requires long series (30 years or more) of crop responses to regional environmental conditions, including variable spatial and temporal characteristics. It is difficult to achieve this with conventional experimentation. That is why we need computer-based analytical tools, such as crop simulation models, geographical information systems (GIS), weather generators, and socioeconomic models.

The objective of this paper is to discuss the use of these technologies to provide fast and reasonably accurate assessments of how cropping systems interact with the environment. These tools require limited but well-targeted experimental information for model calibration and validation, and a suitable resource database (weather, soils, land use, etc.). The latter may be a limiting factor, because complete databases are not readily available in many regions, and large-scale data collection and organization is time-consuming and expensive.

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Cropping Systems Simulation Models

In physical and engineering disciplines, where the underlying principles governing the behavior of the systems of interest have long been known, computer simulation has been extensively used since computers became available. This has not been true in biological sciences, however, particularly in agriculture, where the use of computer simulation models has been much more recent. However, a clear trend toward computer simulation applications in agriculture started during the 1970s, and is strong today.

Simulation models are finding applications in research, teaching, farm and resource management, policy analysis, and production forecasting. Some of the benefits in these areas may be summarized as follows:

- Models increase the level of understanding and provide direction to research.
- Modeling is interdisciplinary by nature, enhancing the integration of research efforts into teams.
- Simulation models are an excellent tool for training, extension, and teaching.
- Models are useful to gain insight into situations where experimental results are lacking or incomplete.
- Models permit us to understand the interaction between cropping systems management, soil, and random weather variability.
- Modeling is an efficient way of obtaining production functions to evaluate the economic impact of agronomic practices and assess risk.

Various crop simulation models are available that may be useful for these purposes. Examples include: the CERES models for wheat, corn, and sorghum, with others under development (Jones and Kiniry, 1986); SoyGro (Jones et al., 1989); PnutGro (Boote et al., 1989); BeanGro (Hoogenboom et al., 1991); SUCROS and other models (Kropff and van Laar, 1993); SORKAM (Rosenthal et al., 1989); COTTAM (Jackson et al., 1990); SIMTAG (Stapper, 1984); EPIC (Sharpley and Williams, 1990); and CropSyst (Stockle and Nelson, 1994).

To support the applications discussed in this paper, models must provide estimates of productivity and environmental impact resulting from long-term simulations of continuous crops and of crops in rotation. Most of these models are set up to simulate one crop, and cannot estimate outcomes from crop rotations. However, efforts are underway to link single models to develop the capability to simulate crop rotations. EPIC, SUCROS, and CropSyst are generic crop simulators that can simulate different crops with a common set of parameters. Of these, EPIC and CropSyst are set up to simulate crop rotations, including simulation of various management options and predictions of environmental impact.

The EPIC model (Erosion-Productivity Impact Calculator) was originally developed to estimate how erosion is affected by cropping systems management; thus, crop growth is represented in this model using a simplified approach. However, modifications of the model to improve simulation of crop growth are under development (e.g., Cabelguenne and Debaeke, 1995). CropSyst (Cropping Systems Simulation Model) was developed with a focus on simulating crop growth response to soil, weather, and management, adding to this the capability to estimate water erosion, residue decomposition, tillage effects and others. Its crop growth description is more detailed than in the EPIC model, but less detailed than some single crop models, because of the need to keep a generic approach. The remainder of this discussion of crop simulation models will be devoted to describing some of CropSyst's capabilities.

Brief Description of CropSyst

CropSyst is a multi-year, multi-crop, daily time-step simulation model of crop growth. It was developed with emphasis on a friendly user interface. It has a link to GIS and a weather generator; a link to economic and risk analysis models is under development. Its objective is to serve as an analytical tool to study the effect of cropping systems management on crop productivity and the environment. For this purpose, CropSyst simulates the soil water budget, soil-plant nitrogen budget, crop phenology, crop canopy and root growth, biomass production, crop yield, residue production and decomposition, and soil erosion by water. These are affected by weather, soil characteristics, crop characteristics, and crop management options, including crop rotation, cultivar selection, irrigation, nitrogen fertilization, soil and irrigation water salinity, tillage operations, and residue management.

The water budget in the model includes precipitation, irrigation, runoff, interception, water infiltration, water redistribution in the soil profile, crop transpiration, and evaporation. Users may select different methods to calculate water redistribution in the soil profile and potential evapotranspiration (ET_p). Water redistribution in the soil is handled by a simple cascading approach or by a finite difference approach to determine soil water fluxes. CropSyst offers three options to calculate ET_p. In decreasing order of weather data required, these are: the Penman-Monteith model, the Priestley-Taylor model, and a simpler implementation of the Priestley-Taylor model that only requires air temperature.

The nitrogen budget in CropSyst includes N transport, N transformations, ammonium sorption, and crop N demand and uptake. Nitrogen transformations of net mineralization, nitrification and denitrification are simulated.

Daily crop growth is expressed as increase in biomass per unit area. The model accounts for four factors that limit crop growth: water, nitrogen, light, and temperature. Leaf area development, root depth, and root density are related to biomass accumulation.

Besides crop growth, the model provides estimates of runoff, soil erosion, fate of residues in the soil, N cycling (including organic and mineral phases), N leaching beyond the crop rooting zone, and fate of pesticides in the soil. Further details on model components and equations are given in the user's manual (Stockle and Nelson, 1994).

CropSyst has been applied to a few crops (corn, wheat, barley, soybean, peas, and sorghum) and regions (western US, southern France, northern and southern Italy, northern Syria, northern Spain, West Africa, and western Australia) with reasonably good results. Fig. 1 shows observed versus simulated biomass and grain yield for spring wheat grown in Logan, Utah under 30 combinations of water and nitrogen levels (Stockle et al., 1994). Fig. 2 compares experimental (symbols) and simulated (lines) values of green area index (GAI), aboveground biomass, evapotranspiration (ET), and N uptake throughout the growing season of a wheat cultivar developed by ICARDA and the national programs of several countries and grown at Tel Hadya, headquarters of ICARDA in northern Syria (Pala et al., in press). Agreement throughout the season is reasonable, providing a good base for adequate simulation of biomass and yield at harvest time. Such predictions are compared with observed values in Fig. 3 (Pala et al., in press), which includes three growing seasons, three levels of water, and two levels of nitrogen. Statistical analyses have indicated a satisfactory performance of CropSyst in these and other evaluations. The model, properly calibrated, appears suitable for the kinds of applications discussed in this paper.

Application of Simulation Models to a Region

Despite efforts to develop process-oriented crop simulation models, CropSyst or any other crop growth simulation model cannot be applied to a specific region without local experimental information and expertise. The model must be calibrated and validated before it can meaningfully be applied. In this process, quality control to ensure the reliability of the available experimental data is extremely important. Also, whenever possible, it is advisable for the research group responsible for the development of the simulation model to interact directly with the users applying it in a given region. This allows timely improvements in the model in cases where it performs poorly.

Weather Generators

Long-term series of weather data are required for the type of computer-based analysis discussed here. These include daily

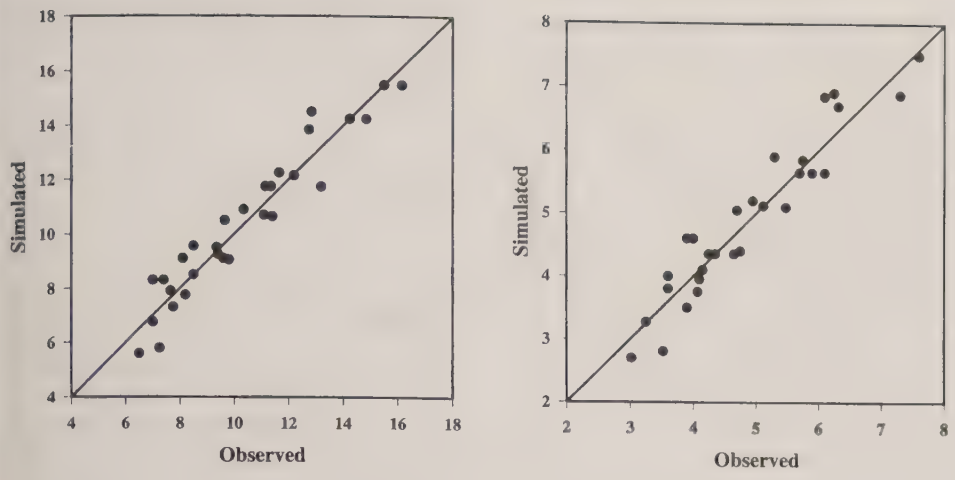

Figure 1. Observed and simulated a) biomass and b) grain yield for spring wheat grown in Logan, Utah under 30 combination of water and nitrogen levels (redrawn from Stockle et al., 1994).

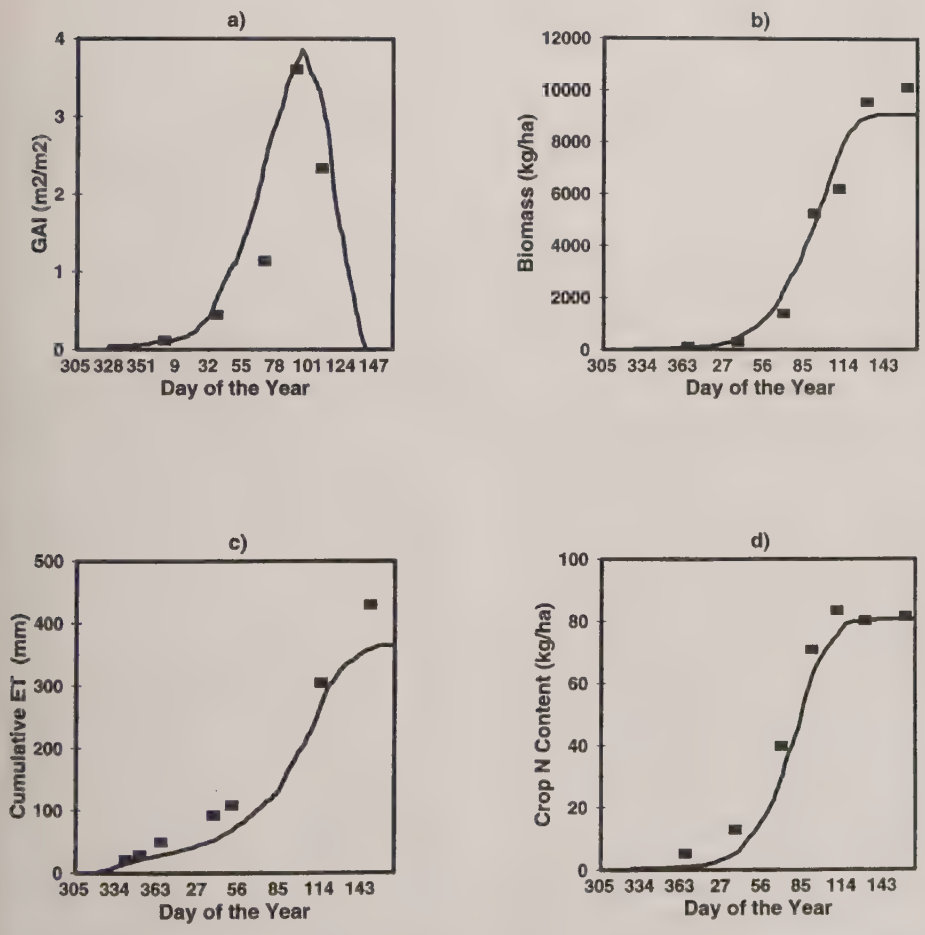

Figure 2. Seasonal distribution of daily simulated data (lines) compared with observed data (symbols): a) green area index (GAI); b) aboveground biomass, c) cumulative evapotranspiration (ET), and d) cumulative nitrogen (N) uptake. Crop is durum wheat grown at the ICARDA headquarters in Tel Hadya, Syria (from Pala et al., in press).

data on precipitation, maximum and minimum temperature, and solar radiation. Sometimes these data are not readily available, or only monthly summaries can be found. In those cases, a weather generator that can simulate long series of weather from a reduced data set can be used.

One generator often used in the US is WGEN (Richardson and Wright, 1984). The modeling group at Washington State University has made several modifications and additions to this model. As a result, CLIMGEN (Campbell, 1990; Ndlovu, 1994) has been developed and tested using a worldwide database. This weather generator can generate precipitation, maximum and minimum temperature, solar radiation, and vapor pressure deficit from minimum data.

CLIMGEN has two components: one that determines weather generation parameters, and a second that generates long-term series of data based on those parameters. To generate weather parameters, it is desirable to have a minimum of 25 to 30 years of daily precipitation data, 10 years of daily temperature, and 5 years of solar radiation. However, monthly summaries with some indication of variability (range, fraction of wet days, etc.) are sufficient for some applications. This variability also can be "captured" from another weather station in a similar region. Another approach is to use some of CLIMGEN's built-in relationships to estimate generation parameters from the site location. These relationships have been determined from a large worldwide database used for model development. Finally, the generator can be used to interpolate data for locations with no information.

Fig. 4 compares weather data generated using CLIMGEN to actual observations of a weather station at the ICARDA headquarters in Tel Hadya, Syria. These results show that when actual data are limited, the use of generated weather is reasonable for the computer-based assessment of cropping system management discussed here. Comparison of model outputs using generated and actual weather data has shown no significant difference for practical applications (e.g., Ndlovu et al., 1993).

Geographical Information Systems

A GIS is a set of tools for collecting, storing, retrieving, transforming, and displaying

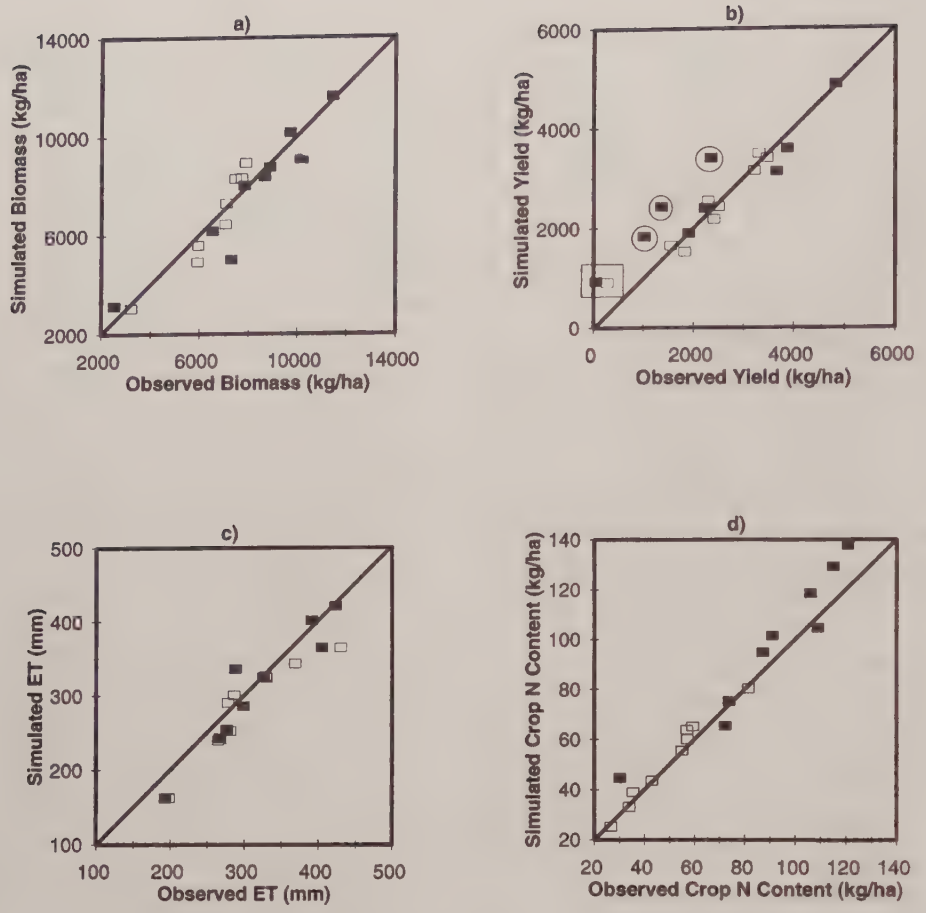

Figure 3. Observed versus simulated a) aboveground biomass, b) grain yield, c) cumulative ET, and d) cumulative N uptake. Crop is durum wheat grown at the ICARDA headquarters in Tel Hadya, Syria, growing seasons 1989/90 to 1991/92 (from Pala et al., in press). Circled symbols show yields for special conditions not accounted for by the model.

spatial data for a particular purpose. Because a GIS allows users to access, transform, and manipulate data interactively, it is a way to study environmental processes, analyze the result of trends, or anticipate the possible results of planning decisions (Burrough, 1986). Since GIS programs became available for microcomputers, varied applications have been developed. For example, a range of agricultural applications was presented at an international conference on "Application of Geographic Information Systems, Simulation Models, and Knowledge-based Systems for Landuse Management" (VPI&SU, 1990).

For the computer-based analytical approach discussed here, GIS programs are a way to store spatially structured data such as soil characteristics, land use, precipitation, and planting dates. These "data layers" are overlapped to produce maps that display the spatial distributions of unique combinations of individual data layers. Attributes associated with each data layer are stored in a database management program, which eventually can be used as input for simulation models. In addition, GIS programs can display simulation outputs of interest. A GIS-CropSyst link has been developed to display a map containing any of the more than one hundred output variables generated by the model. Several utilities for spatially structured data analysis contained in GIS programs can be used for further analysis of these maps.

Software that integrates GIS, simulation, and weather generation technologies will continue to be developed and improved in the future. Practitioners and researchers interested in applying these technologies for assessment of cropping systems management should not underestimate the time and resources required to prepare a suitable database. However, this effort is essential for successful implementation of such a project.

Risk Assessment and Economic Models

Besides the agronomic, biophysical, and physiological considerations related to crop yield and the conservation of bioresources, the evaluation of risk and economic feasibility of dryland agriculture systems is highly important. Risk and uncertainty influence the efficiency of resource use in agriculture and the decision-making process. Risk management is important in evaluating alternative farming practices and deciding which option to select whenever decision outcomes are uncertain, as occurs for most farming situations. The combination of simulation modeling, GIS, and weather generation, coupled with risk analysis models, allows us to evaluate a range of possible events and outcomes, and therefore can help researchers, managers, policy makers, and farmers to make better decisions.

Economic models also can be added to the system. These can be simple budget analyzers or cost-benefit programs of varying complexity, aimed at evaluating the short- and long-term economic feasibility and sustainability of agricultural production scenarios. In addition, more complex socioeconomic models can be linked to the system, such as household/farm behavioral models and watershed/aggregate social welfare models (Deybe and Stockle, 1992). Household/farm behavioral models consider activities, constraints, and transfers within the household/farm to maximize an objective function, where productivity and degradation of resources resulting from household/farm level decisions are determined by the simulation/GIS/weather generator system. This type of analysis can be aggregated to the watershed level, where additional activities, constraints, and transfers among groups of households/farms must be considered.

Preliminary Applications

Some preliminary applications of GIS and simulation technologies have been done at WSU for assessing management of dryland cropping systems. For example,

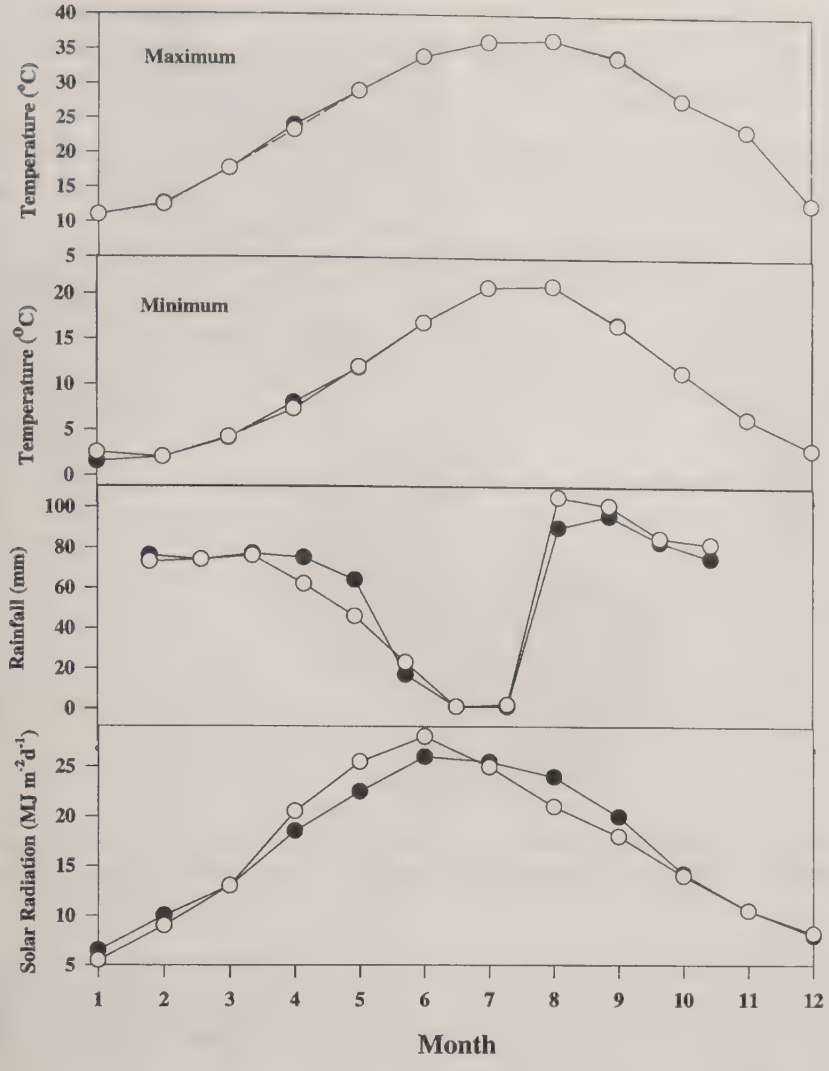

Figure 4. Comparison of weather data generated using CLIMGEN (open symbols) and actual observations (closed symbols) for a weather station at the ICARDA headquarters in Tel Hadya, Syria: a) maximum temperature, b) minimum temperature, c) precipitation, and d) solar radiation. Values correspond to monthly averages of 14 years of daily data. A longer record is required to improve the agreement between observed and generated precipitation.

agroclimatologic variability and risk in millet production in Burkina Faso, West Africa, were assessed in a simple preliminary application (Badini, 1994). Several tables, risk probability figures, and maps were produced. This work helped us to visualize the potential of these tools for regional analyses. A similar analysis is being conducted for wheat management options in a region of about 2,000 km^2 near the ICARDA headquarters at Tel Hadya, Syria (Mustafa Pala, ICARDA, private communication, 1995). Another regional application is in progress for wheat production in the Pacific Northwest.

To illustrate the results that can be obtained by combining simulation, weather generation, and GIS technologies, Fig. 5 shows the distribution of long-term average grain yield and the coefficient of variation for continuous winter wheat in selected dryland counties of the Pacific Northwest. Interpretative maps for analyzing risk, management, environmental impact, and policy implications can be developed from basic simulation outputs.

Computer-based technologies for analyzing agricultural systems have great potential. Comprehensive systems are just emerging that integrate all the aspects discussed here. Continuous improvement is expected, particularly in making the simulation models more accurate and the computer software easier to use. A great deal of communication between modelers and users will be required to accelerate this process.

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Figure 5. Distribution of long-term a) average grain yield and b) coefficient of variation for continuous winter wheat in selected counties of the Pacific Northwest. Light tones represent large values and vice versa. Range of yields is 0. 6 to 5.0 Mg/ha, range of coefficient of variation is 14 to 135%.

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RESOURCES (Cont.)

"Calves, Heifers, and Dairy Profitability," the proceedings from a national conference held in January, 1996, are $30; **"Implementing Pheromone Technology in the Northeast"** is $16; **"Dairy Reference Manual"** is $40; all are available from NRAES, Cooperative Extension, 152 Riley-Robb Hall, Ithaca, N.Y. 14853; (607) 255-7654; e-mail nraes@cornell.edu.

"Taxing Pesticides to Fund Environmental Protection and Integrated Pest Management" by the Center for Occupational and Environmental Health, University of California, Berkeley, is available from California Policy Seminar, 2087 Milvia St., #412, Berkeley, CA 94704; (510) 642-5514.

"Forage Information System" is now available on the World Wide Web at http://www.forages.css.orst.edu/; contact Dr. David Hannaway, coordinator, at Oregon State University, (541) 737-5863; e-mail david@forages.css.orst.edu.

Integrating crop and livestock production in Inland Northwest farming systems

Linda H. Hardesty and James A. Tiedeman

Abstract. *The demand for more ecologically and economically sustainable agriculture arises because we currently integrate products economically in a fashion that distorts ecological relationships. Early farms were ecologically integrated through feeding of forage crops and crop residues to livestock, with livestock contributing draft power and manure for crops. Today we have almost entirely uncoupled plant and animal production, eliminating the contribution that each can make to the productivity of the other. Barriers to integrating farming systems include the large volume of information needed for sophisticated production systems and the lack of infrastructure. Also, many chemicals used on crops have not been evaluated for their safety in food animals. Winter feeding and calving may conflict with crop production cycles; balancing year-round forage supplies is another obstacle. Opportunities include using the Conservation Reserve Program to shift land to livestock production. Domestic demand for meat is changing, and range livestock production is seen by some people as more humane than confinement. Animals fed less grain may be more acceptable in some markets. As agriculture responds to changes in society, ecological integration may become more compatible with economic integration.*

Key words: range, dryland, ecological integration, economic integration

Ecological versus Economic Integration

The environment, crops and production methods of the Inland Northwest are similar to those of many dryland regions of the world. Nevertheless, its lack of livestock is striking to people from regions where dryland crop and livestock production are interdependent components of a single production system.

Integration means to make whole or to bring parts together. In ecological systems, energy and nutrients are the currency. In modern times we have improved the productivity of both animal and plant food production to the point where we take ecological relationships for granted. Instead of relying on decomposition of organic matter to provide nutrients for plant growth, we remove organic matter from the systems and replace lost nutrients with chemical fertilizers. Most food animals are raised to achieve slaughter weights very rapidly through the feeding of grain and other supplements. By substituting economic integration for ecological integration, we have obscured ecological relationships in our present agricultural systems. The Inland Northwest is typical in many ways of how we have come to integrate our products economically in a fashion that, however unintentionally, distorts ecological relationships.

In this paper we describe the relationship between crop and livestock production systems common in the Inland Northwest and explore how they became separated. We then discuss some implications of that separation and identify opportunities for benefiting from the complementarity between crop and livestock production in dryland regions.

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A Brief History of Inland Northwest Agriculture

The original grasslands

The Inland Northwest lies between the Cascade and Rocky Mountains. Most of its current dry cropland originally was dominated by cool season grasses, such as bluebunch wheatgrass (*Agropyron spicatum* [Pursh.] Scribn. & Smith) and Idaho fescue (*Festuca idahoensis* Elm), and by forbs (Franklin and Dyrness, 1988). The soils typically were loams of extraordinary depth and productivity. The north slopes and thinner soils of the ridgetops supported open forests dominated by ponderosa pine (*Pinus ponderosa* Dougl. ex Loud.) and Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco). Riparian zones and concave slopes supported thick motts of shrubs such as chokecherry (*Prunus virginiana* L.), hawthorn (*Crategus douglasii* Lindl.), snowberry (*Symphorocarpus albus* (L.) Blake), serviceberry (*Amelanchier alnifolia* Nutt.), cottonwood (*Populus trichocarpa* Turn. & Gray), aspen (*P. tremuloides*), willow (*Salix* spp.) and wild rose (*Rosa* spp.).

Elk (*Cervus elaphus*), deer (*Odocoileus hemionus, O. virginianus*), and moose (*Alces alces*) were the largest herbivores, although many species of small mammals, birds and insects also depended on the vegetation for food. The region's earliest human inhabitants satisfied their dietary needs by hunting wild game, fishing, and gathering starchy plants.

Early homesteads

Agriculture has been practiced in this region for only about 120 years. The first farms were primarily subsistence homesteads that also produced some products for

sale. Grains, fruits and vegetables were produced using human and animal power. Animals were raised for food (meat, eggs, milk), fiber, and traction. Integration occurred by feeding forage crops and crop residues to livestock, while livestock worked and produced manure for fertilizer. Fall planted cereal grains were grazed by livestock to stimulate tillering and boost yields. Livestock production was supported by use of native range and waste areas where animals were pastured near the farm.

A second livestock industry was transient range livestock production, in which itinerant herds were trailed through the area, fattening on their way to markets in mining regions of north central Washington, Idaho and British Columbia. Supplying fresh saddle horses, draft animals and brood stock to travelers and settlers was another component of the early livestock industry.

The homestead farms illustrate a self sustaining, ecologically integrated production system, while the itinerant herds illustrate loose economic integration. Money from livestock sales often was reinvested in nonagricultural enterprises that eventually strengthened the economic stability of the region and increased demand for agricultural products. In this era, speculation in the livestock industry by East Coast and foreign investors extracted economic and ecological capital from the West. Droughts intermingled with severe winters ended most outside speculation in the livestock industry by the turn of this century, leaving a nucleus of settled, surviving producers. Rangelands were severely damaged by overuse, and native vegetation sometimes was destroyed and soils eroded where sites unsuitable to cultivation were plowed and then abandoned.

As agriculture became more intensive and yields increased, the number of livestock increased because draft animals were essential for powering farm machinery. The large derelict barns in the region are testimony to this era. The sound construction and elegant design of these structures reflect dreams of future prosperity, dependent at least in part on the animals they sheltered. However, the goal of agriculture was shifting from subsistence production to cash crops: small grains, legumes, fruits and forages. Animals were confined to areas incapable of supporting crop production. Thus the steepest slopes and riparian zones became the principal areas for pasturing large numbers of animals year-round. Demand for wood caused many forested areas to be cleared and converted to fields or pasture (Petersen, 1987).

Commercial agriculture

Within 50 years of settlement, most farmers had converted from horse to tractor power, and the region's horse population declined. Cattle and sheep numbers were more stable because they continued to provide a product for home use and cash sale. A growing urban population in the region increased the demand for all agricultural products, and railroads made it easier to meet that demand.

Today, the region's agricultural land is put to its highest and best economic use. To illustrate, 37% of Washington's land area is cropland (Washington Agricultural Statistics Service, 1993), but 58% is cropland in Whitman County, Washington, in the dryland zone, and an additional 31% is rangeland (U.S. Dept. of Agriculture, 1979). The 33,000 cattle and 4,400 sheep in Whitman County generate 13% of the value of the county's agricultural products (Washington Agricultural Statistics Service, 1993). Livestock production is largely confined to uncultivated lands, river breaks, regenerating forests, and some improved pasture. Forages and supplements are either produced locally or purchased within the region.

Only a few farmers in the Inland Northwest continue to raise livestock, but most livestock producers also farm. Often, different family members have primary responsibility for one enterprise or another. Calving and lambing usually are completed before spring cropping activities begin. Commercial livestock enterprises are mostly cow-calf operations. The number of sheep has been declining, with production shifting from range operations to farm flocks.

Today in the Inland Northwest we farm using energy captured long ago in fossil fuels and transported from other parts of the nation and the world. Nutrients are imported from distant sources or manufactured using large amounts of fossil fuel. We ship feeder calves, lambs and grain east and import much of our food from other regions of the nation and from abroad. Livestock are rarely seen on the farmstead or in crop fields. We have managed to uncouple plant and animal production almost entirely, substituting other products for the services that each component could contribute to the productivity of the other.

Economic Integration: Cash and Credit are Currency

Presumably there is an economic rationale for the current situation. Why is it economical to raise barley in Washington State and ship it to Colorado, where it is fed to an animal that may have been born in Washington? After slaughter, that animal may return to Washington as boxed beef to be served at home or in a restaurant, dormitory or fast food establishment. By-products and poorer quality cuts return as pet foods. Lamb in the local grocery store probably comes from New Zealand. Chicken comes from the southeast U.S., where it was fed grain from the Midwest.

Only about 25% of Washington's agricultural products are sold in the state (Washington Agriculture Statistics Service, 1993), but being sold in the state does not insure it will be consumed here. Much of the energy invested in food production today is used to transport inputs, animals and grain that have been processed to some degree. Food production consumes 20.5% of the U.S. energy supply, but only 2.9% goes to produce raw agricultural products (Finley and Price, 1994). More profit is made by adding value to raw agricultural products than in converting natural resources into those products. In 1993, Washington produced $4.4 billion worth of agricultural products, but processing, transport and marketing increased their value to about $20 billion (Washington Agriculture Statistics Service, 1993).

The primary currency in our agricultural systems today is money, not nutrients or energy. We base decisions on economic availability of inputs and economic yields of outputs. The international trade in energy and nutrients has altered energy and nutrient cycles on a global scale, magnifying the complexity of inherently complex ecological relationships. In the process we have concentrated energy and nutrients in certain trophic levels and geographic locations, impoverishing other areas as a result. A further complication is that some of that enrichment is in the form of waste, as in huge accumulations of animal wastes from large confinement livestock production, or accumulations of nutrients in eutrophic waters.

Economists talk about externalities, the costs borne by people other than those who get the economic benefits of an action. An extreme example is the feared global impact of atmospheric changes from burning fossil fuels. Because these are not included in calculating the cost of producing the commodity, the commodity becomes artificially inexpensive and consumption increases in spite of the mounting social cost of production. The average American household spends only 13% of its income on food, the lowest of 11 developed nations recently analyzed (Finley and Price, 1994). Our inexpensive food is subsidized by external costs such as water pollution and soil erosion.

Consequences of Diminished Ecological Integration

The many environmental and human consequences of this lost integration are the subject of increasing concern and have been the motive for recent changes in U.S. agriculture. Among these concerns are water pollution and depletion, soil erosion, watershed deterioration, weed invasions, pests and diseases, food safety, and loss of a relationship to the land (National Research Council, 1989; Edwards et al., 1990).

Because many of these consequences are not obvious, and because global food production and transport systems are so complex, many people do not realize the true costs of food production. In developed countries, people may not even know where their foods originate. Often we cannot determine if our food is locally produced because of the many intermediaries in the process. The increasing frequency of dining out and consuming highly processed foods in the home make it even more difficult to know where food originates.

Humans are a part of the ecosystems they rely on. We sense this intuitively, as expressed in our need to "return to nature." This need may be reflected in environmental activism, home gardening, choosing a rural or suburban homesite, outdoor recreation, or a preference for organic foods. The consumer is the true decisionmaker in America. At the polls, consumers select candidates who will represent their economic and philosophical views about the environment, the economy and other issues in the public sphere. Not all citizens choose to vote, but they all cast numerous "dollar votes" each day in their consumer choices. The consumer who pays a premium for chemical-free beef or certified organic produce is voting for producers who have made nontraditional production decisions. The person who becomes a vegetarian in solidarity with "oppressed" animals also is casting a powerful vote in a system where monetary currency has the final authority. These consumers are expressing a concern for the connection between themselves and the ecosystems that provide their sustenance.

We have converted natural ecosystems with multiple components and functions into units dedicated to production of just one or a few products, supported by outside inputs. Then we intensify our management inputs to cope with the consequences of ecosystems that no longer maintain balanced functions. Now we hope to restore many of those natural functions by encouraging watershed stability, natural pest control, and reduced inputs, yet we also want to maintain high productivity. This implies increasing the complexity and interconnectedness of our agricultural systems. Reintegrating crop and livestock production is one approach that may suit some situations in the Inland Northwest.

Barriers to Integrating Crop and Livestock Production

How might crop and animal production become better integrated to increase the sustainability of our farming systems? As ecologists, our thinking focuses on the laws of conservation of energy and matter. We need to maximize the efficiency of energy conversions, to limit the number of unnecessary conversions, and to consider nutrient cycling to avoid both local scarcity and undesirable concentrations (pollution). Realistically however, there are many barriers to trying to match flows of ecological and economic currency by integrating crop and animal agriculture.

Narrow market for animal products. American per capita meat consumption has leveled out in recent years at about 158 lb/year. However, less of this is beef, lamb and pork and more is poultry than in the past (Fritz, 1994), and more of the beef is ground beef or is imported. The American cattle industry is entering the expansion phase of its multiyear cycle and there is concern that supply will soon exceed demand, depressing prices paid to producers. Promotional efforts by the American lamb industry are helping to maintain the domestic demand for lamb, but not increase it. Producers of pork and poultry have been more successful in increasing demand for new products aimed largely at health conscious consumers and those seeking convenience. To benefit economically from integrating livestock into Inland Northwest cropping systems, producers must invest in an animal product with a promising economic future; the options are limited for producers unwilling to innovate.

Specialization and information overload. A significant barrier to integrating crop and livestock production is the volume of information farmers need because of the sophistication of each production system. Each additional commodity requires new information about production and marketing choices and about interactions and tradeoffs among commodities. Increased management complexity restricts some producers from diversifying even when they know it would be economically advisable (Lawrence and Hardesty, 1992; Hardesty et al., 1993; Lawrence et al., 1992).

Infrastructure requirements. Because our current agricultural systems depend heavily on inputs, choices may be limited by lack of infrastructure for alternative practices, especially for livestock. Fences, corrals, chutes, sheds, watering facilities, improved pasture, and stock trucks are expensive, long-term investments. Unlike much other farm equipment, few of these can be leased, rented or hired out. A survey of Washington landowners established that lack of access to livestock or livestock handling facilities constrained their use of agroforestry systems that include livestock (Lawrence and Hardesty, 1992; Hardesty et al., 1993; Lawrence at al., 1992).

Agricultural chemicals. Agricultural chemicals can be another obstacle to integrating crop and livestock production. Many chemicals used in crop production have not been evaluated for their persistence in food animals. Although they may not be a hazard, lack of approval is a regulatory obstacle to the conscientious farmer. Because of the vast array of chemicals used in Inland Northwest cropping systems, it is costly to evaluate practices such as feeding crop residues to livestock. This inhibits introduction of livestock into areas where chemicals are

used, as does the risk that stock water will be contaminated. When chemicals are applied by air, just being near the treated area can be a problem for livestock producers.

Balancing forage supplies. A major obstacle to further integrating livestock in our farming systems is balancing year-round forage supplies. The typical livestock producer in this region buys or raises hay for winter feeding, uses native range or pasture for spring grazing, often transports stock to forest range or distant native ranges in the summer, and uses crop residues or rangeland in the autumn. Currently 61% of cattle forage and 90% of sheep forage in the US comes from grazing land and only 5% from crop residues (U.S. Dept. of Agriculture, 1989). Where there is no access to rangeland, feed must be raised on the farm or purchased. Demand can only be modified to a limited degree while maintaining a productive herd of cows or ewes. Continually changing the herd size wastes forage and misses markets when market conditions and weather fluctuate.

Land for livestock production. Since the turn of the century, the land available for livestock grazing in the Inland Northwest has been restricted largely to steep, dry or rocky sites, marginal cropland, regenerating forests or the driest forest sites, and riparian zones. Use of riparian zones as pasture has devastated many watersheds, with consequences that are just becoming widely known. Concern about water quality and supply, as symbolized by degraded riparian zones, is a leading reason for a national effort to remove livestock from public land (Jacobs, 1991; Rifkin, 1992). Suitable land must be available for animals even if forage is provided from other sources. This includes sheltered, well-drained sites for winter feeding and clean, sheltered sites for calving or lambing. Access to water often is a constraint in distributing animals on the land. Although current farm programs have taken some cropland out of production, most programs restrict the use of idled land for grazing and haying.

Labor availability and management conflicts. Highly specialized production systems often have inflexible labor demands in which intense activity alternates with relative leisure. In our cropping systems we know what seasonal labor demands will be, but the exact dates vary by as much as a month from year to year, depending on weather. Human labor has largely been replaced by machinery, yet no surplus labor exists. Over half the farms in Washington State are small farms with part-time operators (Washington Agriculture Statistics Service, 1993). Only 3.8% of the state's labor force works in agriculture and forestry combined, and the average farm operator is 50.6 years old (Washington Agriculture Statistics Service, 1993).

The labor demands of any additional enterprise should correspond to lax periods in current production systems; ideally, they also should be tied to weather to accommodate seasonal variability in crop-related labor demands. Furthermore, the total labor requirement should be low. For example, a cattle producer might buy only young cows as replacements instead of the more typical heifers because they require less assistance at calving than first-calf heifers. Another strategy is to buy feeder lambs in the spring, pasture them in orchards, and slaughter them before the green forage supply runs out to avoid the labor demands of lambing and winter feeding. Winter feeding, calving and lambing may conflict with the crop production cycle.

Efficiencies of scale. Like other American agricultural enterprises, livestock production has adapted to economies of scale. For example, the total cost of fencing a pasture is the same whether the pasture contains 6 or 60 animals. Therefore, the cost per head is reduced with more animals. Livestock buyers prefer uniform lots, which requires producers to raise an adequate number of animals of uniform size and quality to receive the best price. Such economies of scale may not be available to the producer who operates on a small scale to diversify the farm. Although the average Washington cattle operation is small (26 head, Folwell et al., 1991), there are formal and informal opportunities for producers to cooperate to achieve economies of scale.

Opportunities for Integrating Livestock into Inland Northwest Cropping Systems

Opportunities on the production side

The Conservation Reserve Program. The Conservation Reserve Program of 1985 presented an important incentive to shift land from cultivation to future livestock production. The program is intended to reduce soil erosion by paying farmers to convert cropland to permanent vegetative cover for a contract period of 10 years. Both haying and grazing are prohibited during this period, but the program did create an opportunity to establish permanent vegetative cover with an eye on future grazing opportunities. Currently there is considerable discussion about the future of these lands as the 1995 Farm Bill is being drafted. Many experts believe that CRP plantings can properly be used by livestock while meeting the program's conservation objectives. Currently, about 14% of Washington's dry cropland is enrolled in this program. However, the vegetation established on some of these sites restricts their forage value (Smith, 1993). Often the grass species seeded were selected strictly for conservation value, or the choice was limited by the available seed. Thus, many of these lands will produce less forage than they are capable of producing, although they can still add to the local forage base when current contracts expire.

Animals for vegetation control. Grazing animals can control unwanted vegetation on agricultural and forest land. In the 1980s, herbicide use on forest plantations was restricted. Herded sheep and sometimes cattle were used instead (Halloin, 1990). Sheep and goats are used to maintain firebreaks and control brush on some shrublands, and even to improve browse conditions for wintering big game species. Currently, livestock are being used to control noxious weeds and to reduce herbicide use and cultivation in orchards (Hardesty and Howell, 1993), and to replace burning in grass seed production (Harriman, 1993). Often, animals cannot be made to graze target plant species heavily enough to achieve the desired results without sacrificing animal production. Therefore, livestock producers sometimes are paid to graze their livestock instead of having to pay for forage.

Underutilized forage sources. Livestock producers are not the only ones who can benefit from integration. Farmers can lease their range or pasture, and sell crop aftermath or other forages to neighbors who own livestock. One large sheep producer in Washington brings his ewes to breeding condition on dropped leaves in orchards. This highly nutritious forage (Hardesty, unpublished data) is available to him at no cost.

The orchardist benefits because residue that harbors pathogens and rodents is removed from the orchard floor and replaced with nutrients from feces and urine.

Another possibility is to use moderate quantities of forage or wasteland on a farm to produce meat for household consumption. More energy and nutrients stay on the farm and less cash leaves. Production of specialty meats is another option. Beefalo, bison, ostriches and similar birds, and some game species can bring new revenue, although this requires an initial investment in technology and market development.

Improved technology. Sometimes, improved technologies can help producers integrate crops and livestock. For example, the cost of permanent fencing might have deterred some farmers from raising livestock before New Zealand style electric fencing became widely available. These fences can be permanent or temporary and are very effective in restraining trained livestock, allowing greater flexibility in containing animals at reasonable cost. Continued development of integrated pest management strategies that rely less on chemicals to control crop pests may make a comparable contribution to improved integration of production systems.

Opportunities on the demand side

Changing demand for meat. Although the total domestic demand for meat is not likely to change soon, the composition of the demand continues to change. Fast foods, eaten in the home, restaurants, or on the go, represented half of all U.S. meals in 1985 (Meyers, 1985). The meat needed for these products usually is processed more than for traditional meals. Lean forage-fed meat satisfies this market better than the grain-fed meat used for steaks, roasts and chops. Demand for inexpensive, lower quality beef has created a market for imported meat, leading to the controversial concern that Latin America's forests are being destroyed to provide hamburgers for Americans (Meyers, 1985; Rifkin, 1992; Meister, 1993).

Consumers' health concerns. Another growing market is health conscious consumers who do not want meat from animals fed antibiotics and growth hormones. Consumers are willing to pay a premium for meat that is certified to satisfy their health concerns. Profit in these markets depends on quality and known origin. Consumers may trust the quality of a local product, creating a profitable niche for more fully integrated operations where less of the profit flows to enterprises between the farm and the table. Since the 1970s, beef self-sufficiency in the Northwest has increased from 47 to 96% (Folwell et al., 1991).

Demand for beef finished to a lower grade. A related issue has to do with public concerns that feeding grain to animals puts them in competition with hungry humans, favoring the wealthy who can afford meat over the less fortunate who may not have enough food to thrive (Rifkin, 1992). Animals fed less grain may be more acceptable to consumers who feel this way, to health conscious consumers and to fast food manufacturers. Range livestock production often is justified as using plant energy not otherwise available for human consumption. In reality, most slaughter animals spend only a small part of their lives on the range, although rangelands are a major source of calves and lambs for feedlots (Meister, 1993). There is also a desire to have even grain-fattened animals consume less grain than in the past. Therefore, the market for forage-fed livestock is expanding.

Animal welfare concerns. Another concern among some segments of the U.S. population is the welfare of animals and the ethics of livestock production. Many people feel so strongly that producing livestock for meat is ethically wrong that they have stopped consuming meat products. Others who still eat meat care about how the animal was treated. A recent study found that range feeding is seen as more humane than raising animals in confinement (Banner, 1993). This view might be extended to forage-fed animals. It may also lead consumers to prefer locally raised food products from trusted producers, a preference reflected in the growing popularity of farmers' markets and local food cooperatives.

Conclusions

Clearly, integrating livestock and crop production is neither simple nor appropriate for every farm and farmer. Opportunities must be evaluated in relation to the objectives and resources of each farm. As a society, we have come to recognize that sustainability cannot be considered solely as either economic or ecological survival. Rather, the two must be integrated. As conditions change, we always need to reexamine past decisions in light of new knowledge and changing human values. Although this is not always a comfortable process, it is a source of hope.

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Committee Report Addresses "Problems" of Agricultural Concentration

The report of the USDA Advisory Committee on Agricultural Concentration, released recently, addresses the "problems and concerns" caused by concentration and vertical integration in agriculture, including "distorted price discovery, unequal access to vital market information, environmental degradation, and perhaps most disturbing, dysfunctional interactions between producers, handlers, packing plants, and retailers and distributors."

USDA Secretary Dan Glickman announced the formation of the committee in February and asked it to report on its findings, determinations, and recommendations for addressing concentration and any of the adverse impacts of concentration.

"We find these issues complex and highly charged," the committee wrote in its report, *Concentration in Agriculture*. "The issues elicit strong views and concerns about the balance of economic power, the use of government power, and personal freedom."

Among the issues cited in the report are the environmental concerns and social costs connected with concentration, particularly in vertically integrated operations. "The increasing size of livestock operations and processing plants has led to growing public concerns about environmental effects associated with these large scale facilities," the report said.

"While pollution and odor have always been problems with livestock farming, the corporate face exacerbates the neighbors' problems. First, with the large size of these operations and lagoon storage, the smell is greater, both from storage and disposal. Second, owners do not always live on the farm and share the problems as do traditional farmers. Water problems are similarly exacerbated by vertical integration."

The report recommends that "major policy efforts should be directed to creating an atmosphere of open disclosure of basic operating facts, including many aspects of price discovery, earnings levels of packers and feeders, environmental management concerns, and contract terms between integrators and producers."

A Minority Views report, signed by six of the committee's 20 members, makes several recommendations about environmental and vertical integration:

- Strengthen rules for animal feedlots to make them consistent and effective in addressing all aspects of pollution (as recommended in the report), including odor, water, and air pollution, and to prevent bidding wars between states willing to sacrifice their environmental quality.
- Review all contracts and arrangements between large feedlots and packers for restraint-of-trade violations, including exclusive dealings and price discrimination.
- Vigorously enforce the Clean Water Act to assure compliance by feedlots at the same level as other industries with similar environmental impact.
- Prohibit packer ownership, operation, management, or financing of any livestock (including swine but excluding poultry) production or feeding operations.

Commenting on the report, Secretary Glickman said that he and President Clinton "believe that there must be a fair and equitable balance of power in the marketplace; that free and open competition must be preserved and enhanced; that more openness and transparency will help the market work better. We are committed to promoting a system of American agriculture in which unfair trade practices are not tolerated, and in which family farmers and ranchers can continue to make a good living on the land."

For a copy of the report, call the USDA Office of Communications at (202) 720-2798.

Better Row to Hoe Wins Gold Award

A Better Row to Hoe, a report by the Northwest Area Foundation on the economic, environmental, and social impacts of sustainable agriculture, received the Gold Award in the special report category in this year's Wilmer Shields Rich Awards for Excellence in Communications, sponsored by the Council on Foundations and the Communications Network in Philanthropy.

"The foundation carefully considered its audiences and got the report out to them. The message is: Sustainable agriculture works," one judge said of the report. Copies of the report and executive summary are available free of charge from the Foundation, 332 Minnesota St., #E-1201, St. Paul, MN 55101; (612) 224-9635.

Role of economic analysis in the evaluation of new dryland technologies

Douglas L. Young

Abstract. *An evaluation of agricultural systems often involves multidisciplinary teams that include crop scientists, animal scientists, soil scientists, pest control specialists, agricultural economists, and others. Agricultural economists can improve the technical quality and comprehensiveness of agricultural systems research in six major areas: budgeting and investment analyses; whole-farm and institutional factors; risk considerations; aggregate effects on crop and livestock prices; society-wide welfare effects of technical or policy changes; and economic values of environmental and other nonmarket effects. Economic analysis has been part of several successful multidisciplinary research efforts in the United States Pacific Northwest. These have covered soil conservation, integrated pest management, sustainable agriculture, crop rotation choice, and beef ranch management. As an example of institutional influences on economic outcomes, one study showed that the structure and selectivity of United States commodity programs have favored conventional over low-input rotations. Regarding risk management, an appropriate "package system" including conservation tillage, a diversified crop rotation, and adequate chemical weed management was shown both to sustain profitability and to reduce income fluctuations. Properly designed economic analysis can make similar contributions to identifying successful dryland agricultural technologies throughout the world.*

Key words: Pacific Northwest, dryland agriculture, risk, multidisciplinary research

Managing successful dryland production systems requires knowledge of soils, crops, livestock, pests, and socioeconomic considerations. Single-discipline approaches to resource management problems can result in solutions "a mile deep and an inch wide." Solutions that omit important components of the system often will be unacceptable to farmers (Johnson, 1987). For example, solutions to weed problems may conflict with soil conservation objectives. Socioeconomic factors such as credit shortages or cultural constraints may impede solutions to livestock management problems.

This paper discusses the potential contributions that agricultural economists can make to multidisciplinary agricultural systems research. It draws on my experience on successful multidisciplinary research teams concerned with soil conservation, pest management, cropping systems, and cattle ranch management in the United States Pacific Northwest (PNW). This experience has confirmed that profitability is a central concern to most farmers and ranchers.

Agricultural economists can improve the quality and comprehensiveness of agricultural systems research in six areas:

- Conducting sound budgeting and investment analysis of alternative technologies and systems
- Incorporating whole-farm factors and institutional realities into system evaluations
- Adding risk considerations to the analysis
- Considering aggregate price effects of new technologies or policies
- Considering society-wide welfare effects of technical or policy changes
- Estimating economic values of environmental and other nonmarket effects.

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Budgeting and Investment Analysis

Agricultural scientists and farmers often are eager to compute the returns, costs, and profitability of promising new technologies or production systems. To ensure that results are comparable from study to study and region to region, standard cost accounting procedures must be used (Boehlje and Eidman, 1984). Unfortunately, researchers sometimes use different accounting procedures, making it impossible to compare the results of different studies unless the original economic and production data are available.

Economists refer to noncash costs, such as the cost of unpaid family labor or farm-grown seed, as "opportunity costs." These items are valued at their next best use, if there is one. For example, the cost of family labor would be the wage that would be received for that labor in alternative employment. When comparisons are made, the cost of a certain input, such as labor, should typically be included for all options even though labor may be a cash cost for one option and an opportunity cost for the other. An exception would occur if the decisionmaker explicitly desires to use "returns over cash costs" as the profit measure to be maximized.

"Fixed costs" of assets such as machinery and land are costs that do not vary with the level of production. In contrast, "variable costs" such as fuel, labor, seed, and livestock feed vary directly with the amount of land or livestock in production. Fixed or "investment costs" for machinery include: depreciation; interest (actual and opportunity); taxes; housing; and insurance. The last three items are not always present, but depreciation and interest costs will always be

present. Depreciation represents the part of a fixed asset that is used up, or depreciated, each year. For many machines, depreciation depends primarily on age. The interest charge represents interest actually paid or the forgone interest earnings on the farmer's capital tied up in the machine. The fixed cost of using land is rent paid, or the forgone rent on land used by the owner.

Fixed costs must be included in a budget whenever the technologies or practices being analyzed cause a change in fixed costs. For example, switching to a no-tillage system may require the farmer to buy a no-till drill and sell other tillage machinery, which changes the fixed costs of machinery. However, when the systems being compared have the same fixed costs, it is not necessary to calculate and subtract them, provided the results are interpreted as measuring only the net returns over variable costs for the different systems, not net returns over total costs.

An important decision at the outset is whether the analysis should cover one or several years. Systems involving perennial crops, large-scale irrigation systems, greenhouses, and other long-term investments require analyzing costs and returns over several years. For example, the total costs of establishing an orchard should be amortized (spread out) over the productive life of the orchard. By analyzing the time pattern of cash outflows and inflows of a large investment such as an apple storage facility, the analyst can calculate the present value, internal rate of return, or other multiyear profitability criterion (Weston and Brigham, 1993; Boehlje and Eidman, 1984). Computing the present value of an investment requires the decisionmaker to select a "discount rate," namely the interest rate that could be earned if the funds were invested in their next best use.

Whole-farm and Institutional Factors

Most dryland farms have several enterprises that interact with each other. Changes in one crop in a rotation, for example, can influence weed or disease problems of other crops in the rotation. Farm machinery often is shared among different enterprises, and its costs must be allocated properly. Adjustments in cropping rotations that affect the amount of after-harvest forage may influence the livestock carrying capacity of the farm. All such multiple-enterprise factors should be incorporated when evaluating the profitability of proposed management changes.

Participation in government farm programs can have especially important consequences for the cropping system. For example, a winter wheat/spring barley/spring pea conservation tillage system in eastern Washington was identified as both profitable and soil conserving (Young et al., 1994). Unfortunately, many farmers in this area of eastern Washington have been using a wheat/pea rotation and thus have had very little barley "base acreage" in the government farm programs. Historically, barley base acreage, based on past planting patterns, determined how much barley farmers may grow while continuing in the profitable government farm programs. Consequently, an inadequate barley base precluded some growers from profitably adopting the wheat/barley/pea rotation. In other parts of eastern Washington, the lack of barley base precluded some farmers from adopting flexible spring barley cropping for soil conservation purposes.

Government cost sharing for conservation practices can be a strong incentive for adopting them. For example, the U.S. Dept. of Agriculture recently has provided up to 75% cost sharing for constructing new solar powered electric cross fences for better rotational grazing management on PNW cattle ranches. Cost sharing also has encouraged ranchers to fence cattle watering ponds and to siphon the water into troughs below the ponds. This stabilizes the adjacent land and provides cleaner water. Such cost sharing or other incentives must be included when examining the private profitability of rotational grazing, livestock water improvement, or other subsidized practices. Because many PNW cattle ranches are only marginally profitable, the fencing and water projects would not have been widely adopted without cost sharing.

Economic analysis also can provide useful information to policymakers in designing cost sharing and other government incentive programs. Subsidies can be set appropriately by computing the subsidy level at which desired conservation or other practices become equal in profit to current practices.

Risk Management

To survive, farmers and ranchers in dryland areas must pay close attention to income risks as well as to long-run average profitability. A new production system with significant probability of crop failure two years in a row could threaten some farmers.

A recent research project in the PNW compared flexible spring cropping to the traditional winter wheat/summer fallow system in low rainfall areas (Young and van Kooten, 1989). In the flex system, farmers' decision to grow soil conserving spring crops is based on measurements of spring soil moisture. In some regions, the flexible spring cropping systems earned competitive long-term average returns and offered substantial soil conservation gains, but were riskier. The spring cropping systems also created a "crush" of work in the spring, whereas winter wheat/summer fallow spread the work load for labor and machinery more evenly over the cropping season. Consistent with this analysis of economic risk and machinery management, few farmers in the study regions have adopted the flex crop systems.

Fig. 1 shows how economic analysis can portray the long-term average profitability and the riskiness of different production systems in a single graph (Young et al., 1994). The vertical axis displays variability over six years of experimental results for each of twelve cropping systems, while the horizontal axis displays their average profits. The twelve systems include combinations of two cropping rotations (continuous wheat and wheat-barley-peas), two tillage systems (conventional tillage and conservation tillage) and three weed management levels (minimum, moderate, and maximum). Fig. 1 reveals a rare but welcome combination of risks and returns. Systems RM2 and RM3, which are wheat/barley/pea systems with conservation tillage and with moderate or maximum weed management, respectively, generate both the highest level of average returns and low risk. Often, new technologies that improve profit also increase risk. Also, traditional technologies with lower profits often survive because they are less risky.

Economic analysis of agricultural systems should go beyond simply measuring risk. It should identify useful options for managing the risk (Patrick, 1992). Risk

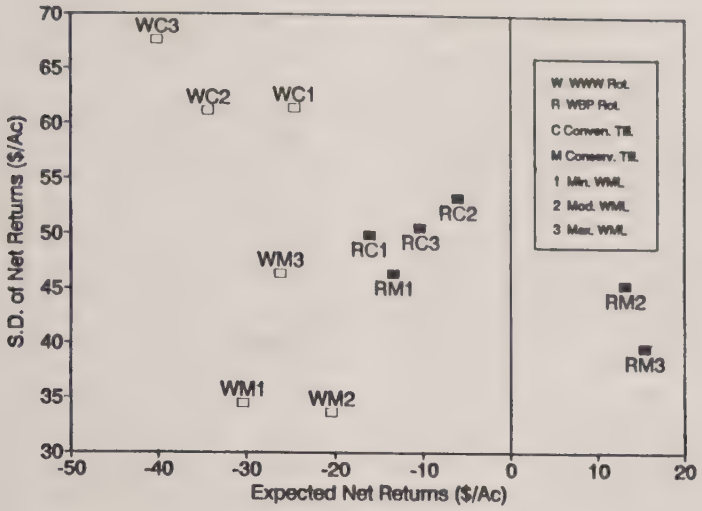

Figure 1. Average profitability and economic riskiness of 12 cropping systems, Pullman, Washington, USA, 1986–91. Source: Young, et al., 1994.

management strategies can be divided into two categories: those that transfer or share the risk with other parties, and those that manage the risk within the farm. Strategies for transferring or sharing risk include: renting on a crop share basis, so that the rent decreases in years of poor harvests; crop insurance; hedging on the futures market; and forward contracting for fixed prices. Historically, PNW grain growers have transferred risk by participating in federal wheat and barley programs, under which the payments per bushel increase during years of low crop prices.

Diversification among several crop and livestock enterprises is a well-established way to manage risk within the farm. When there are several enterprises, yields and prices for some crops and livestock may remain strong while others fall. In modern U.S. agriculture, however, machinery cost savings and managerial efficiencies from specializing in one or a few profitable crops often have outweighed the risk management advantages of diversification. U.S. farms were much more diversified and self-sufficient before World War II. Diversification, often through intercropping that is possible with hand harvesting, remains a successful risk management tool in some developing countries.

Many dryland farmers rely heavily on good machinery maintenance and some excess capacity in machinery to manage risk. These practices reduce the probability of costly machinery breakdowns, which could delay planting or harvesting during critical periods. Another risk management practice is for farm family members to pursue off-farm jobs or to have off-farm investments. Further economic stability is provided when off-farm family wage earners can return to the farm during periods of peak labor demand, especially planting and harvest.

Aggregate Effects on Prices

When budgeting the profitability of new technologies or cropping systems that are likely to be adopted by only a small fraction of producers, one can assume that increased supplies will not reduce market prices. Returns then can be computed simply by multiplying the commodity price times the quantity produced, and subtracting production costs. Of course, even in this "simple" situation, estimating the price can be difficult if the time horizon of the study extends into the future.

When analyzing new technologies or cropping patterns that are likely to be widely adopted, economic analysis requires adjustments in commodity prices. Aggregate (market-wide) price effects are likely when the commodities are produced primarily in one region. For example, because production of bluegrass seed is centered in the PNW, prices would decline if yield or the area in production increased.

Society-wide Welfare Effects

Although the farm-level profitability of a particular agricultural system or practice is central to its acceptability to farmers, it also is important to analyze its economic consequences beyond the farm. Consumers and taxpayers, not just producers, incur benefits and costs from agricultural changes (Gardner, 1988). Agricultural economists are increasingly called upon to evaluate the society-wide economic effects of agricultural technologies and policies.

As an illustration of society-wide welfare measurements, Fig. 2 evaluates government subsidization of a particular crop, such as wheat, without controls on its supply. Line

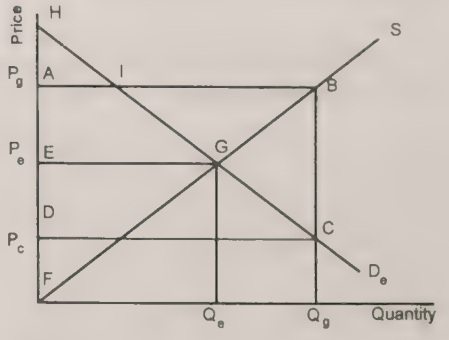

Figure 2. Standard economic welfare analysis.

FGBS presents the aggregate national supply curve for the commodity. $HIGCD_e$ represents the aggregate (domestic + foreign) demand for wheat. This deliberately simplified example assumes the government establishes a support price, P_g, that is guaranteed to producers, but without set-aside requirements, loan rates, or other provisions. The government pays farmers the difference between the market clearing price (P_c) and the support price (P_g) on all production. Under the indicated supply function, farmers will produce a quantity Q_g in response to price P_g. If government intervention is ended, production will fall to Q_e and the market clearing price will rise to P_e.

"Producer surplus," an economic measure of farmers' welfare, is measured along a supply curve reflecting the aggregate of short-term marginal costs. Geometrically, producer surplus is the area between the supply curve and the price line. It shows the net returns to fixed factors of production. "Consumer surplus" is an economic measure of net benefits to both domestic and foreign consumers. Geometrically, consumer surplus is the area between the demand curve and the price line. In Fig. 2, "consumer surplus" falls by the amount of the quadrangle EGCD when government subsidies are ended. Consumers pay higher

prices and consume less (assuming no imports) without the price subsidy. Producer surplus will be reduced by the amount ABGE. Against these losses are balanced the taxpayer savings represented by the rectangle ABCD. Taxpayer savings from ending government intervention exceed the collective gains to consumers and producers by the triangle BCG. BCG represents the "dead weight loss" of market intervention by the government, or the net efficiency gain of converting to free markets.

Economic Valuation of Nonmarket Effects

A complete social welfare evaluation also requires evaluating the policy's nonmarket benefits and costs, which frequently are imposed on the environment or the community. Net nonmarket effects should be added to the net market benefits depicted in Fig. 2. It is difficult to estimate the value of clean water, fertile soil, diverse wildlife, stronger community/cultural ties, and other nonmarket benefits. To place a value on environmental amenities, economists have used "contingent valuation" survey questionnaire techniques (Mitchell and Carson, 1989), or they have measured indirect costs like travel costs to recreational sites. Other economists have used "natural resource accounting" to estimate the "depreciation cost" of resource-depleting development plans and policies (Faeth et al., 1991).

The market and nonmarket effects of specified agricultural policies were separated into the following components for a U.S. case study (Painter and Young, 1994):

- Producers' profits, which were divided into net returns to landlords and net returns to farm operators;
- Impacts on consumers from food price changes;
- Costs to taxpayers for commodity and conservation programs;
- The economic value of nonmarket environmental damage or benefits of the agricultural changes induced by the policy.

Table 1 uses the preceding framework, excluding consumer effects, which were small, in reporting the impacts of six U.S. commodity program proposals for a PNW study region (Painter and Young, 1994). Each policy was evaluated under two scenarios:

1. Both conventional and alternative (low input sustainable) rotations are available;
2. Only conventional rotations are available.

Societal welfare (total economic and environmental results in Table 1) shows modest differences among policies; however, the distribution of costs and benefits varies greatly among them. For example, the "free market" policy (no programs) greatly reduces costs to taxpayers, but the incomes of farm managers and landlords fall sharply.

In some less developed countries, and perhaps in developed countries also, it would be desirable to quantify the consequences of proposed technologies and policies on even more specific segments of society. These might include large versus small farms, landless agricultural laborers, urban elites versus urban poor, and export industries.

Table 1. Predicted average economic and environmental indicators when maximizing retur ns to management under various policy scenarios, 1991-95 expected prices, Washington-Idaho Palouse (Painter and Young, 1994).

Policy/Rotations	Returns to Management ($/A)	Returns to Land ($/A)	Taxpayer Cost ($/A)	Erosion Rate (tone/A)	Off-site Erosion Damage ($/A)	On-site Erosion Damage ($/A)
1990 Farm Bill						
All rotations	6	53	23	5.6	14.0	1.3
No alternative rot.	–6	61	23	6.1	15.1	1.4
1990 Farm Bill, 40% Flex						
All rotations	2	46	15	4.1	10.1	1.0
No alternative rot.	–8	58	16	6.1	15.1	1.4
1990 Administration						
All rotations	11	52	28	5.3	13.1	1.3
No alternative rot.	1	57	28	6.5	16.2	1.6
Decoupling						
All rotations	5	43	23	2.1	5.2	0.5
No alternative rot.	–1	61	23	6.3	15.5	1.5
Recoupling						
All rotations	15	43	36	2.1	5.2	0.5
No alternative rot.	–5	61	23	6.3	15.5	1.5
No Programs						
All rotations	–9	36	0	2.1	5.2	0.5
No alternative rot.	–19	53	0	6.3	15.5	1.5

Conclusions

This paper identified six areas where agricultural economists can make useful contributions to agricultural systems research. These include performing sound budgeting and investment analysis, incorporating whole-farm and institutional factors, adding risk considerations, enumerating aggregate market effects on prices, enumerating society-wide welfare effects of technical or policy changes, and evaluating nonmarket effects. Economic analysis in all these areas can help identify successful agricultural technologies in the United States and internationally.

However, neither economic analysis alone nor any other single disciplinary approach is sufficient. The validity of economic analysis of agricultural technologies depends on the quality of the physical and biological data. Biological, physical, and social scientists must work together to ensure successful analysis of agricultural systems.

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Organic Sales Increase by 21 Percent — Total More than $2 Billion in 1995

Organic sales increased 21.7 percent to total $2.8 billion in 1995, exceeding $2 billion for the second year in a row, according to *Natural Foods Merchandiser* (June, 1996). Sales last year increased by about $500 million from 1994 sales, marking the sixth year in a row that organic sales have increased by more than 20 percent.

The organic market continues to grow because of several factors, including a widening consumer base, aggressive expansion by natural products retailers, greater acceptance in the mainstream sector, and increasing organic farm acreage, according to the magazine. "Industry members say they are seeing a growing number of younger, family-oriented consumers seeking out organic products," the magazine said. "Customers are responding to a greater visibility of organic products in their own right and to more thoughtful media coverage."

Final Appropriations Conference Restores ATTRA Funding

The final appropriations levels approved by a U.S. House-Senate conference for the 1997 Fiscal Year restored funding for the Appropriate Technology Transfer for Rural Areas (ATTRA), but cut funding for the Sustainable Agriculture Research and Education (SARE) program and the Sustainable Agriculture Technology Development and Transfer Program (SATDTP). Here is a summary of what the conference approved for sustainable agriculture programs:

SARE: An $8 million appropriation was approved; FY96 funding was $8.1 million. **SATDTP:** A $3.3 million appropriation was approved; FY96 funding was $3.4 million. **ATTRA:** A $1.3 million appropriation was approved; the House had deleted the funding; FY96 funding was $1 million. **OFPA:** A $500,000 appropriation was approved for the Organic Foods Production Act; FY96 funding was $600,000. **WRP:** Final language for the Wetlands Reserve Program limits enrollment to 130,000 acres, 30,000 more than last year; it also allows additional acreage to be enrolled with non-federal money. **EQIP:** $200 million was approved for the new Environmental Quality Incentives Program, as mandated in the farm bill. **Fund for Rural America:** A $100 million appropriation was approved for the new fund, as mandated in the farm bill.

Half of Organic Farmers Plan to Increase Acreage, Survey Finds

Forty-nine percent of certified organic farmers plan to increase their organic acreage, according to a new survey by the Organic Farming Research Foundation of 3,480 organic farmers across the country. Of those surveyed, 40% plan to increase the number of products they grow and market, and 52% expect to expand the number of marketing outlets used.

"The survey results offer startling statistical examples of how organic farmers are straining to meet the extraordinary demand for organic products," said the Foundation.

The top three research priorities of those surveyed were the relationship of growing practices to crop quality and nutrition, crop rotations for fertility and pest management, and consumer demand for organics.

Other top priority research topics were the relationship between plant nutrition and pest resistance, cover cropping, green manures, and animal preventive health. Nearly 63% of respondents conduct their own on-farm research projects.

Sole proprietors or family partnerships comprised 83% of those surveyed; on average, respondents have been farming a little more than 16 years, 9 of them organically.

When asked about on-farm water quality, 56% of respondents said they were strongly or somewhat concerned about bacterial contamination of their water; 63% said they were strongly or somewhat concerned about chemical contamination of their water.

For a copy of the complete survey results, send $10 to Grower's Survey 95, OFRF, P.O. Box 440, Santa Cruz, CA 95061; or call (408) 426-6606.

Five Members Named to Organic Standards Board

Four appointments and one reappointment to the National Organic Standards Board (NOSB) have been announced by Agriculture Secretary Dan Glickman. Newly appointed to five-year terms are Joan D. Gussow, Piermont, N.Y., a member of the Editorial Board of the Wallace Institute's *American Journal of Alternative Agriculture* (consumer/public interest); Stephen P. Pavich, Delano, CA (farmer/grower); Elizabeth S. Lydon, New York, N.Y. (consumer/public interest); and Jean Afterman, Oxnard, CA (environmentalist).

Robert B. Anderson, Middleburg, PA (farmer/grower) was reappointed for a five-year term. The 15-member NOSB advises the Secretary on implementation of a certification program for producers and handlers of agricultural products that have been produced using organic methods.

BOOK REVIEWS

Biological Control: Benefits and Risks. Edited by H.M.T. Hokkanen and J.M. Lynch. 1995. Cambridge University Press, 40 W. 20th St., New York, NY 10011-4211. xxii+304 pp. $74.95, hardcover.

This book is a collection of 28 articles on the risks and benefits of various forms of biological control. The articles are based on presentations made at a workshop held in 1992 in Finland, convened to discuss this subject with emphasis on genetically modified organisms. The articles are grouped into four divisions: 1) biological invasions; 2) classical biological control; 3) augmentative biological control; and 4) use of genetically modified organisms.

As a biological control scientist, I am always interested in new books on the subject. Reading this book left me with the immediate impression that it has a very weak overall structure. It grew out of a collection of topics that are only loosely tied together, and there is no integration or momentum in the book as a whole. It is just a box filled with 28 separate articles.

Taken individually, I found that the chapters fell into four categories. One category consisted of those that very competently reviewed established topics within biological control, but that offered me no new insights or surprises. These included the chapter by D. Greathead (Chapter 5) on the risks and benefits of classical biological control; by B. Blossey (Chapter 8) on screening of insect biological weed control agents for host specificity; by R.-U. Ehlers and A. Peters (Chapter 11) on the use of nematodes; by R.deC. Canon (Chapter 17) and by J. Huber (Chapter 18) on the development of new ways to use *Bacillus thuringiensis* and baculoviruses, respectively; and by J.A. Cullen and M.J. Whitten (Chapter 26) on the economics of classical biological control projects. For readers new to the discipline, these chapters will be useful vehicles to gain quick familiarity with these topics. For the already informed, they will open no new doors.

A second category of chapters, which discussed particular systems, seemed too specialized for a book seeking to explore broad themes. Examples include: J.-P. Aeschlimann's (Chapter 7) on introduction of parasites for control of certain weevils in New Zealand; Chapter 14, by D.N. Dowling and others, which provides a very technical description of a particular plant disease antagonist and some genetic issues related to its use; K. Tsuchiya's (Chapter 20) on the use of *Pseudomonas cepacia* as a biocontrol agent; and R.D. Lumsden and J.F. Walter's (Chapter 25) on the development of *Gliocladium virens* as a biocontrol agent. These chapters seem so narrowly focused that their connection to the book's themes could be overlooked by a casual reader.

The third category was of chapters that in my opinion just don't work. D. Pimentel (Chapter 2) attempts to assess the risk of introducing genetically modified organisms by looking at how many species of crop or ornamental plants have become pests. Since many of the problems discussed in this chapter arose when the organisms mentioned were separated from the natural enemies that regulate their populations, I was unconvinced by the basic thesis of this chapter—that these introductions had something to teach us about the risks posed by genetically modified organisms. J.C. van Lenteren (Chapter 3) discusses invasion theory, and tries to link it to risks posed by genetically modified organisms. Again, I found this linkage to be of limited value, especially since the conclusions about the characteristics of "good" invaders are themselves debatable and hence not a solid foundation for judging the risks of genetically modified organisms.

Finally, sprinkled among the other chapters were six that I found very stimulating! In the order they appear, these are the following.

K.R. Hopper's article (Chapter 6) on estimating the potential impacts of parasitoid introductions on endangered invertebrates was very interesting to me. This is a topic I have to grapple with from time to time in discussions with insect conservationist colleagues who sometimes are fearful of biological control. Hopper's discussion was a useful exercise, showing how the potential risks of particular biological control projects could be evaluated with respect to a particular set of endangered species. I particularly was struck by his comment that if all insect species (not just endangered ones!) were to be protected by this same stringent standard, biological control of insect pests as we know it would likely be impossible.

J. Waage's discussion (Chapter 9) of the use of exotic pathogens as biopesticides surprised me by pointing out a theme I had entirely overlooked: that pathogens for biocontrol commonly are exchanged widely around the world, and once commercialized are not treated as exotic, although often they are exotic in many countries where they are sold. This situation is based on the cosmopolitan distribution of many of these pathogens at the *species* level. Waage points out that *pathotypes* may be less cosmopolitan, so that distributing them widely could have consequences for nontarget invertebrates. A new and interesting perspective!

The analysis by D.A. Andow, C.P. Lane and D.M. Olson (Chapter 10) of the risk of *Trichogramma* releases was another revelation. I had thought of some risks of *Trichogramma* releases, for example to commercial uses of Lepidoptera such as silkworm cultures and cottage-industry farming of birdwing butterflies in Papua New Guinea. However, I had never focused closer to home on whether such releases would pose risks to endangered species of native Lepidoptera in North America. Andow et al. present a very credible analysis of risks to Karner blue populations (a species that is something of a cause célèbre in the U.S. inverterbrate conservation community).

R.J. Crook and D. Winstanley (Chapter 21) provide a very interesting discussion of genetically modified baculoviruses and the risks of recombination after release. This topic may be well known to virologists, but I found the treatment very informative. Another thoughtful discussion is offered by C.H. Wearing and H.M.T. Hokkanen (Chapter 23), covering the risk that resistance to *Bacillus thuringiensis* will develop from incorporation of Bt genes in crop plants.

Finally, M.J. Whitten (Chapter 24) presents a structured, thoughtful analysis of the general types of risks that genetically modified organisms might pose. For those of us who are not up on the very latest doings in the

GMO world, this is an excellent summary of recent events and their bearing on the risk evaluation argument.

In conclusion, if this review seems a little disjointed, it has accurately caught the tone of the book. Nevertheless, the book offers some thought-provoking chapters and some well-done treatments of more familiar topics, and is worth having on your bookshelf.

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Control of Crop Diseases. 2nd edition. By W.R. Carlile. 1995. Cambridge University Press, 40 W. 20th St., New York, NY 10011-4211. 145 pp. $19.95, paper.

This book is a revision and expansion of a book first published by Edward Arnold in 1988. This edition is intended to provide new information on methods for diagnosis of plant diseases and an expansion of information provided earlier on fungicides and their use in plant disease control. As with the first edition, this edition is a broad introduction to the subject of plant diseases and their control, intended mainly for growers and other practitioners in the European Union (E.U.), particularly the United Kingdom.

It is organized into eight chapters, starting with a very short introduction. Chapter 2, "Major crop diseases in the UK," has most of the conceptual information on the symptoms and causes of plant diseases, including color pictures of symptoms and descriptions of life cycles of the pathogens. The author might also have given some attention in this chapter to a more general discussion of the nature of plant diseases for the benefit of the intended audience. It would have been useful, for example, to explain that a *pathogen* is an organism with ability to cause disease, whereas a *disease* is a process involving an intimate interaction between plant and pathogen that begins with infection and ends with the pathogen reproducing on or within the infected tissues or the dead plant. Different authorities have different definitions but all recognize, or at least should recognize, that disease is a process and a pathogen is an organism.

Unfortunately, Carlile is careless in his use of the terms "disease" and "pathogen." The book is replete with statements such as "spread of diseases," when he means spread of the pathogen, "stem canker also survives on rape stubble," when it is the pathogen responsible for stem canker that survives on rape stubble, and "the disease [fireblight of pear and apple] can be carried . . . by honey bees," when he means that the bacterial pathogen responsible for fireblight can be carried by honey bees. This is all too common in popular and semipopular writing, and has led to the unfortunate practice of lumping plant diseases under the term *pests*. Pathogens are pests, but diseases are processes involving two organisms—host and pathogen. This confusion occurs with plant diseases, but never with animal and human diseases: one cannot imagine cancer or hoof and mouth disease called a "pest."

Chapter 3 is on the art and science of diagnosis of plant diseases, including the use of the newer molecular methods such as DNA tests and monoclonal antibodies. Chapter 4 discusses disease control through eradication, quarantine, certification procedures, and laws. Many pathogens that once were important are controlled today because techniques are available first to detect them on seeds or other planting material, and then to eliminate these sources of inoculum with the help of certification or legislative measures.

Chapter 5 is a very general discussion of disease control by cultural and biological methods. Enough information is available on this subject for this to have been the longest chapter in the book, but in fact it is one of the shortest (9 pages). Subjects such as crop rotation and biological control receive little more than one or two paragraphs each.

Chapter 6, on the development and use of crop cultivars with resistance to diseases, is one of the best in the book. It gives details on the sources and kinds of resistance, methods used to develop cultivars with resistance, and the various strategies used to deploy genes for resistance. Along with cleaning up the planting material and using cultural practices such as crop rotation, breeding for disease resistance is another major success story in the history of plant disease control. Many people do not realize that major U.S. crops, including wheat, corn, soybeans, barley, oats, and sorghum, are grown with almost no protection by foliar fungicides, other than in emergencies, because cultivars developed for U.S. conditions have been bred for resistance to the major fungal leaf diseases. Wheat stem rust has been kept under control in the U.S. Great Plains through plant breeding since the early 1950s.

Chapter 7, which deals with fungicides, is the longest chapter (33 pages). Almost every fungicide approved for use in the E.U. (also in the U.S.) is discussed in some detail, including an illustration of its chemical structure. The E.U. in general and the U.K. in particular have turned increasingly during the past 25 years to fungicides as a major method for controlling diseases, including leaf diseases of wheat. Although the U.K. once was a world leader in developing wheats with disease resistance, the cultivars available in the U.K. today have been selected for their ability to yield when protected by fungicides. In direct contrast, U.S. wheat cultivars continue to be selected for their ability to yield well when *not* protected by fungicides. The result after many years is that the wheat industry in the U.K. is now totally dependent on foliar fungicides, while in the U.S. it is not.

Chapter 8, the final chapter, discusses the U.K. situation mainly with respect to the use of fungicides, under the title "Current trends and future prospects." However, almost as if to justify continued use of fungicides and to play down the future of plant breeding for disease resistance, Carlile refers to the substances that account for disease-resistant plants as "naturally occurring pesticides." It may be true that the resistance response or "incompatible" plant-pathogen interaction involves chemicals produced by the plant, but these substances are not pesticides, nor should they be treated as pesticides. The inherited forms of resistance naturally present in plants or introduced into cultivars by breeding involve a complex interplay of gene expression and cascade of chemical events expressed as a phenotype. Despite extensive research over many decades, no clear relationship has been established between the production of a particular toxic chemical substance in plant tissue and the resistance response of that plant tissue to infection or disease development.

Fungicides will always play an important role in the protection of crops against plant diseases, in the same way that medicines will always play an important role in the protection of people against diseases. Disease control with chemicals is shifting

toward materials that are increasingly specific and that work at remarkably low dosages. The most useful information in this book is the detailed information it provides on fungicides. However, the trend in the U.S. and increasingly throughout the world is toward integrated pest and disease management, also referred to in a recent report from the National Research Council (1995) as *ecologically based pest management*. In this approach, pesticides are among the last rather than first tools used to manage diseases or combinations of pests and diseases. While this book contains a great deal of the information needed for a more holistic approach to disease management, it says very little about integration. Carlile instead has written just about the components, leaving it to the practitioner to assemble the system.

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Reference

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How EC and World Bank Policies are Destroying Agriculture and the Environment. By Jack W. Bond. 1996. AgBé Publishing, PO Box 1, B-1050 Brussels 5, Belgium. xvi+152 pp. $39.00, hardcover; $29.00, paper.

Since World War II, a massive transformation of world agriculture has affected all aspects of agroecosystems: the technology, economics, social structure, politics, and international trade issues relating to agricultural production have all been vastly altered. World food output has nearly tripled during this period. Agricultural trade has expanded rapidly; Europe has shifted from a net importer to a net exporter, and some Asian countries have achieved food self-sufficiency as a result of the rapid spread of Green Revolution high-yield grains. The overall import requirements of the developing world, however, have steadily grown, with increasing dependence primarily on North American grain exports.

Some view the record since World War II as an epochal success story, refuting Malthusian visions of population outrunning food supply. Others have emphasized the negative side of the Green Revolution: social dislocation, environmental damage from intensive agriculture, and increasing dominance of giant corporations in agricultural production and trade. Jack Bond takes his stand with this latter group. His focus is on the institutional changes that have taken control of agriculture out of the hands of farmers and transferred it to bureaucrats, multinationals, politicians, and bankers — to the detriment of sound agricultural practices, consumers, the environment, and the developing world.

Bond, a retired international civil servant and rural development adviser, writes in a popular rather than academic style, sometimes verging on the polemical. He is equally critical of bureaucratic control of agriculture and of unrestrained free markets and free trade. In his view, both are incompatible with local control, intimate knowledge of agroecosystems, and a long-term perspective, all of which he argues are essential for a socially and environmentally sustainable agriculture.

Much of the book focuses on the development of European agriculture during the last half-century. Bond argues that in the wake of World War II there was an immediate, practical goal: reconstruction of physical infrastructure and the achievement of self-sufficiency in agriculture. Once this goal was reached, there was a need for a new orientation — towards sustainable agricultural systems. However, in the course of expanding production a fundamental change occurred in the nature of farming systems, which Bond describes as a shift from experience-led to science-led agriculture. No longer could farmers determine for themselves the best techniques of production, using primarily organic manures and crop rotation. Instead, they became dependent on corporate-produced fertilizers and pesticides, and were forced by government policies to grow certain favored crops in monocultures. At the same time, the political control of farming organizations passed to agribusiness and corporate interests. Neither the government bureaucrats nor the corporate leaders had much interest in, or knowledge about, the farm-level issues related to sound agricultural practices. Thus, when the need for increased production was replaced by a need to address problems of environmental damage and social dislocation, the political structure was ill-suited to respond.

Bond details numerous examples of corporate and government-led agricultural fiascos. The European Union's (EU) Common Agricultural Policy has led to widespread environmental damage throughout Europe as a result of its push for intensification of agriculture. Thousands of miles of hedgerows have been destroyed, soils compacted, and water supplies polluted with excessive nitrogen and pesticides. Acidification of soils, mobilization of heavy metals, and contamination of water supplies with toxins and pathogens, all are extensive and increasing. In the Netherlands, nitrate concentrations in drinking water exceeded European Union standards beginning in the 1980s and have continued to rise rapidly since then. Soil compaction and destruction of drainage have led to rapid runoff and extensive flooding in Germany, France, the Netherlands, Belgium, and the United Kingdom.

Falling food prices—often cited by economists as proof of the success of "modernized" agriculture—are viewed by Bond as damaging to the integrity of the farm sector, especially in developing countries. Cheap food imports undermine domestic production and move countries away from the goal of self-sufficiency; they also force farmers to compete in a world market by using intensive techniques regardless of their long-term environmental costs. Giant agribusiness corporations like Cargill dominate the world market and wield the political clout to shape trade agreements and multilateral bank policies to their liking.

The world agricultural market also leads to distortion of third world economies through concentration on export crops. Bond cites the example of the trade in cassava between Thailand and the European Union. Expansion of Thai cassava production for export, strongly promoted by the World Bank, has led to widespread exhaustion of soils and displacement of small farmers from their lands. According to Bond, five million ha of land have been destroyed and 70% of Thai smallholders driven off their land. Meanwhile in EU countries like the Netherlands, cheap cassava feed has promoted a rapid expansion of factory farming of pigs and cattle. The concentration of huge numbers of animals in feedlots has led to an unmanageable problem of water pollution by manure runoff. Thus, the export of nutrients from Thailand to the Netherlands both depletes Thai soils and pollutes Dutch water. The logic of the market is insensitive to this

gross and increasing ecological imbalance, as well as to the disruption of Thai society, which contributes to the growth of drug and prostitution problems in Bangkok.

Bond offers many more specific examples of the pernicious effects of EU and World Bank policies on developing nations. Wheat imports in Burundi and EU-subsidized beef in Togo have undermined the local pastoral economies, creating dependence on EU surpluses. In Botswana, promotion of beef exports has led to overgrazing and range degradation; World Bank promotion of cacao plantations in West Africa and elsewhere led first to rainforest destruction and then to economic catastrophe for the exporting countries, as cacao prices plummeted as a result of predictable overproduction.

Rural destruction through "modernized" agriculture affects Europe as well as the developing world. Bond recounts how 58,000 Spanish dairy and cattle farmers are being forced out of business by lower-priced industrial farm output encouraged by EU subsidy and quota policies. He criticizes EU and World Bank bureaucracies for their remoteness from farmers, their failure to understand grassroots agriculture and the importance of diversity, and their insensitivity to the effects of their policies. While he favors sweeping away much of the transnational bureaucracy that promotes these damaging policies, he is no supporter of unfettered free markets. Rather, he feels that political organization is essential to bring the concerns of farmers and of local communities back to the center of policy making. He looks to nongovernmental organizations (NGOs) to help integrate agricultural and environmental policies, but feels that most NGOs still lack the necessary experience and competence to take on this task.

While strong on denunciation of current failed policies, the book is limited in its suggestions for alternative paths. Like others, Bond calls for a new development paradigm, based on a local focus and an effort to make agriculture compatible with both biophysical and socioeconomic environments. He opposes current European policies of land set-asides combined with intensive production; instead he favors extensification, which necessitates better land use planning and appropriate uses for marginal lands. While he generally advocates the use of organic techniques, he sees intensification and increased fertilizer use as essential for the developing world, especially in areas of high population pressure.

Is it possible to envision an environmentally friendly agriculture that offers farmers a decent income while supplying the needs of growing populations at moderate prices? Bond suggests that it is, but leaves many of the details — and potential policy conflicts between the needs of farmers, consumers, and the environment — unexplored. He does make a convincing case that we can do much better than we do now by abandoning many of the disastrous policies now so enthusiastically pursued by the European Union and the World Bank. The shaping of possible alternatives is left sketchy, and no doubt others will step in to analyze the potential for a truly sustainable agriculture, which surely will require sweeping changes both in institutions and in techniques.

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LETTERS TO THE EDITOR

Regional grazing schools in Ohio

The article by Rust et al., "Intensive rotational grazing for dairy cattle" (*AJAA* 10(4):147-151) covers a topic that is very timely not only for dairy farmers, but also for other livestock producers. Intensive rotational grazing, strip grazing, Voison grazing, and rationed grazing are similar systems for improving pasture management to reduce production expenses for meat and milk and to enhance farm profitability.

We have found that to maintain production, management must be substituted for the decrease in inputs with these grazing systems. Therefore, we use the term "Management-intensive Grazing" (MiG), coined by Jim Gerrish of the University of Missouri. With all the fervor for this system, a concern has developed for educating producers about the management principles related to MiG so that they can reap all its benefits.

Since 1986, several events, programs, and workshops relating to MiG have been conducted in Ohio. In 1994, an Integrated Forage Management (IFM) team consisting of state specialists, Extension agents, and Natural Resource Conservation Service representatives was formed in Ohio to focus educational programs on improving the profitability of Ohio farmers and enhancing the environment through efficient use of forages. One goal of the IFM team was to develop an expanded curriculum and offer "Pasture for Profit" schools on a regional basis.

Ten teaching outlines were developed by IFM team members for the schools. The topics include: What is Management-intensive Grazing?; Evaluating Your Resources; Goal Setting; Understanding Plant Growth; Soil Characteristics and Fertility; Forage Species Selection and Management; Matching Plant and Animal Requirements; Paddock Design and Water Systems; Economics of Grazing; and Feeding Dairy Cattle on Pasture. Each teaching outline included a script and either 35mm slides or overhead transparencies, and scripts developed by members of the IFM team for other instructors throughout the state. In addition, each outline had a corresponding set of educational materials incorporated into a notebook and provided to each participant. Finally, each teaching outline included a factsheet that will be distributed statewide.

These outlines were covered in two or three sessions consisting of five to eight hours of classroom instruction. Then a "hands-on" outdoor meeting was provided on a case farm to allow participants to gain practical experience from the instructors and experienced graziers. During the outdoor meeting, participants were divided into teams that competed to design the best plan for the case farm. An experienced grazier assisted the team, answering questions while the teams walked the farm to understand and appreciate all its resources.

Then, teams designed a system to optimize forage use, reduce soil erosion, improve water quality, minimize forest use by livestock, minimize labor, and improve

profitability. The final part of the program allowed the teams to present their water system design, fence layout, and forage species selection for comment and discussion by the other participants and the instructors. To provide information and support after the meeting, each participant was given a subscription to a bimonthly grazing newsletter and was encouraged to attend a local grazing council that meets regularly.

Eleven "Pasture for Profit" schools were conducted in 1994 and 1995, involving over 400 producers. These regional schools offered an enhanced instructor/student ratio of 1:15, compared with 1:50 at previous statewide conferences.

Through a pre- and post-test instrument, participants were asked to list their top three reasons for considering MiG. Before the school, producers' reasons were to extend the grazing season, increase productivity, and utilize resources better. After participating in the school, graduates were asked what they thought about MiG. Of the 134 respondents, 94% planned on implementing MiG and thought it would significantly increase their net returns. Also, 71% considered the environmental benefits of MiG (better land and soil management) to be a major advantage.

The Ohio Regional Grazing Schools provide an introduction to the art and science of MiG. With this background, participants have a basic understanding of plant and animal science, as well as grazing management. Participants also are provided with a resource notebook and are able to network with other graziers from the school and with local grazing councils.

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Nitrogen: It doesn't just go away

In an otherwise fine article on environmental policy and swine manure management (AJAA 10(4):163-166), Dana Hoag and Fritz Roka make a serious omission in their accounting of nutrient cycling in swine manure management. Without intending to, they imply that nutrients in anaerobic lagoons are "reduced." In fact, as the authors state, from 70 to 95% of the nitrogen in anaerobic lagoons is volatilized to the surrounding atmosphere (Midwest Plan Service, 1985). Nutrients are not reduced—the N is released into the atmosphere as ammonia, and soon returns to the soil in precipitation and dryfall. Perhaps the authors believed that the gaseous N was transformed to N_2, but this does not occur.

Data showing increased atmospheric N deposition related to livestock production are available from the Netherlands. Currently, the Netherlands receives an annual average of 45 kg/ha of N from atmospheric deposition, which is 10 times the natural background. The greatest deposition (50 to 65 kg/ha) occurs in the southeastern part of the country, where the livestock industry is the most intensive (Berendse et al., 1993; Sutton et al., 1993). On a local scale, soil nitrate increased and pH decreased in the immediate vicinity of a poultry farm (Berendse et al., 1993), demonstrating that much of the ammonia "lost" to the atmosphere during manure storage did not go very far. This eutrophication has caused substantial damage to forest, dune and heathland ecosystems. Conservation area managers are now scratching their heads, trying to figure out ways to truly "reduce" nutrient loads in their endangered habitats (Marrs, 1993).

It is important to acknowledge that nutrients are never "lost", just redistributed. Because of this misperception, operators of anaerobic lagoons routinely and quite legally discharge nutrients to the environment.

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Authors' response:

Laura Jackson makes an important point about our not accounting for nitrogen cycling at all levels. While we agree with her, this was not a central issue to the question we addressed.

We were starting from the premise that hogs will be produced and that in turn they will produce manure. Our question was related to cost effectiveness and policies to direct nitrogen off the farm through volatilization and crop uptake. The term "lost" in this context simply means it is removed from the farm and is no longer a management problem for the producer.

Ms. Jackson points to a need to examine further how society chooses to deal with nitrogen from manure. Currently farmers face more criticism for nitrogen going into water than that which is volatilized; they are simply making good economic decisions. Her comment emphasizes a need to examine whether we have inappropriately transferred nitrogen from one environmental sink to another.

This is a systems problem that will require contributions from many disciplines. We think that we have made a contribution by expanding the way nutrient management has been addressed. We hope that our work will stimulate further research that addresses the comments by Ms. Jackson and others.

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Guide for Authors

The American Journal of Alternative Agriculture (AJAA) publishes original research on biological, physical, or social science aspects of alternative agriculture. We particularly welcome multidisciplinary studies, but papers from a specific discipline also are invited. However, since AJAA readership is much broader than for a single-discipline journal, highly specialized terminology should be explained or avoided. The significance of a statement, or the reasoning behind a conclusion, may have to be spelled out more than in a more specialized journal. See Vol. 5, No. 1, pp 2 & 3, for an explanation of the various categories of articles.

Units

Research papers should use the International (SI, or metric) system throughout. Occasional use of common unit equivalents in parentheses is permitted.

Title page

The title page should give the following information (all flush left): 1) title of the paper; 2) names of authors; 3) affiliation and office address of authors, and 4) disclaimers and publication number, if any. See examples in this issue of AJAA.

Abstract

The abstract should be 200 to 400 words suitable for readers from a broad range of disciplines. It should avoid highly-specialized terminology that might be appropriate for a single-discipline journal. Take particular care that the significance of the work is made clear, even to readers from a different field.

Key words

Provide subject matter key words suitable for use in scientific indexing.

Reference list

When citing material that has been covered in more than one format, such as the typescript of a conference presentation and a journal article, preference should be given to the version that is most readily available, and that is likely to remain so. Generally this means standard publication channels, such as books, journals, and regular government report series. Unpublished or informally-published material should be cited only when no alternative form exists.

References should be listed in alphabetical order by author's name, and by year for a particular author (with letters after the year if needed). If a sole author is also the lead author of papers with multiple authors, use the following order: single author (by year); two authors (alphabetically by second author's name); three or more authors (by year). Repeat the author's name for each reference. Give the names of all authors in the reference; never use "et al."

Use full names of journals, institutions, conferences, etc., except for extremely familiar abbreviations like "Dept." Remember that an abbreviation familiar to you may not be familiar to readers outside your field. If in doubt, write it out.

The reference list uses no quotation marks, italics, boldface, or underlining. Only the names of books and periodicals are in initial capitals. Names of papers, book chapters, pamphlets, and bulletins are not capitalized.

Citing references

Cite references in the text by last name and year, with chapter or page numbers if the reference is a book or lengthy report. For two authors, give both names. Do not use "et al." unless there are at least three authors.

Footnotes

AJAA does not use bibliographic or substantive footnotes. All bibliographic references should be at the end of the text. Instead of substantive footnotes, include the material in the main text or consider eliminating it.

Manuscript preparation

The entire manuscript, including abstract and references, should be typed on one side of standard-size paper, double spaced, with margins of at least one inch all around. Starting with the title page, label all pages in the upper righthand corner with the lead author's last name and the page number. Do not use hyphens unless the hyphen is part of the word.

Tables should fit on one page, be numbered consecutively with Arabic numerals, and be on a separate sheet. Every figure and table should be mentioned at least once in the text.

A detailed guide to formatting is available from the editor (address below).

Submission of manuscripts

Submit four high-quality copies to William Lockeretz, Editor, American Journal of Alternative Agriculture, School of Nutrition Science and Policy, Tufts University, Medford, MA 02155. The cover letter should state that the manuscript is an original contribution that has not been published elsewhere in substantially the same form, that it is not currently under consideration elsewhere, and that permission has been obtained for any copyrighted material used.

How you can help support the scientific and educational needs of a sustainable agricultural system

A growing number of Americans have become concerned about the long-term sustainability of our food production system. Farmers and agricultural scientists are among those raising questions about the growing dependence of modern farming on nonrenewable resources, the depletion of our resource base through soil erosion, and heavy reliance on chemical fertilizers and pesticides. Continued heavy reliance on farm chemicals is questioned because they have become an expensive production input. Their widespread use also raises questions about human and animal health, food quality and safety, environmental quality, and the continued demise of the family farm.

Low-input alternative farming methods address these economic and environmental challenges. Alternative production systems point the way toward more profits, more individual choice, and long-term sustainability for our food system. More must be done to develop effective ways to make sure research, education, and information sources are readily available to farmers who want to adopt these techniques.

The Henry A. Wallace Institute for Alternative Agriculture needs your help in meeting this challenge. We are a nonprofit tax-exempt research and education organization established in 1983 to encourage and facilitate the adoption of low cost, resource conserving, and environmentally sound farming methods. We work directly with government agencies, colleges and universities, producer groups, and other institutions that provide research, education and information services to farmers.

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